NASA Conference Publication 2094

Conference on Fire Resistant Materials: A Compilation of Presentations and Papers

Sponsored by NASA Headquarters
Held at
Boeing Commercial Airplane Company
Seattle, Washington
March 1-2, 1979

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Space Administration

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PREFACE

The proceedings of the NASA Fire Resistant Materials Engineering (FIREMEN) Program held at Boeing Commercial Airplane Company, Seattle, Washington, on March 1-2, 1979 are reported in this NASA Conference Publication. The purpose of the conference was to discuss the results of research by the National Aeronautics and Space Administration in the field of aircraft fire safety and fire-resistant materials. The program topics include the following:

1. Large-scale testing
2. Fire toxicology
3. Polymeric materials
4. Fire modeling

Contributions to this compilation were made by representatives from NASA Headquarters, NASA-Ames Research Center, NASA-Johnson Space Center, Boeing Commercial Airplane Company, Lockheed California Company, Southwest Foundation for Research and Education, Solar Turbines International, Jet Propulsion Laboratory, University of Utah, and ISOVOLTA Company.

D1

N79-31167

R. BRICKER

AIRCRAFT FLAMMABILITY

FULL SCALE POOL FIRE TESTS

OUTLINE

- PRIMARY OBJECTIVES
- THREE PHASE PROGRAM
  - OBJECTIVES
  - APPROACH
  - ENVIRONMENTAL CONSIDERATIONS
- SCHEDULE
- STATUS OF REQUIRED MATERIALS
- OPTIONS TO COMPRESS SCHEDULE

PRIMARY OBJECTIVES

- CONDUCT FULL SCALE TEST WITH 737 FUSELAGE BY END OF 1980
- DEMONSTRATE EVACUATION TIME INCREASE TO 5 MINUTES MINIMUM
- SHOW THAT EXTERIOR FIRE WILL NOT PENETRATE AN INTACT CABIN FOR 5 MINUTES
- SHOW THAT CLOSED CABIN WILL NOT HAVE EXCESS SMOKE OR TEMPERATURES ABOVE 400°F
- DEMONSTRATE THAT FIRE IN CABIN OPENING WILL NOT PROPAGATE THROUGHOUT CABIN

THREE PHASE PROGRAM

- PHASE I

  CHARACTERIZE AND SIZE POOL FIRES FOR SUBSEQUENT TESTS

- PHASE II

  TEST THREE 10' X 10' FUSELAGE PANELS AT 45° ANGLE OVER POOL FIRE

- PHASE III

  CONDUCT FULL SCALE TEST(S) W/737 FUSELAGE

PHASE I - POOL FIRE CHARACTERIZATION

- OBJECTIVES

  - MEASURE THERMAL OUTPUT OF 5' X 5', 10' X 10', AND 15' X 15' POOL FIRES (VARIES W/FUEL AREA AND DEPTH)

  - DETERMINE FIRE GEOMETRY (HEIGHT, WIND EFFECTS)

  - DETERMINE MINIMUM SIZE POOL FIRE FOR 10' X 10' PANEL TESTS (HEAT FLUX $\geqq$ 14 BTU/FT^2 - SEC TEMP $\geqq$ 1600°F)

  - IMPROVE IGNITION TECHNIQUES (JET A1 RELATIVELY DIFFICULT TO IGNITE)

  - PROVIDE DATA FOR SELECTION OF FULL SCALE POOL FIRE FOR 737 TEST AND VERIFICATION OF FIRE SEVERITY

PHASE I

APPROACH

- USE EXISTING JSC FIREFIGHTERS TRAINING SITE (TTA HAS PORTABLE DATA ACQUISITION EQUIPMENT AVAILABLE)
- INSTRUMENT WITH CALORIMETERS AND TC'S
- UPGRADE CURRENT IGNITION TECHNIQUE TO PROVIDE RAPID FIRE SPREAD OVER POOL SURFACE (SWITCH TO JP4 IF SIGNIFICANT IGNITION PROBLEMS OCCUR)
- EIGHT TO TEN TESTS (FIVE TO TEN MINUTE DURATION)

ENVIRONMENTAL CONSIDERATIONS

- PROBLEM--AIRCRAFT FUEL FIRE PRODUCES CONSIDERABLE BLACK SMOKE
- CONSIDERATIONS
  - SMOKE CONSISTS MAINLY OF CARBON PARTICULATES
  - LOW LEVEL OF TOXIC GASES (MAINLY CO)
  - TESTS OF SHORT DURATION AND LIMITED IN NUMBER

    BECAUSE OF IGNITION TECHNIQUES DEVELOPED BY TTA, AVAILABILITY OF INSTRUMENTATION AND NEED FOR REAL TIME DECISIONS AND MODIFICATION TESTS SHOULD BE RUN AT JSC

  - TTA IS FUNDED TO SUPPORT PROGRAM

PHASE II - PANEL TESTS

OBJECTIVES

- PROVIDE VERIFICATION OF FIRE BARRIER MATERIALS
- VERIFY INSULATION RETENTION TECHNIQUES
- MEASURE TEMPERATURES ACROSS TEST PANEL

APPROACH

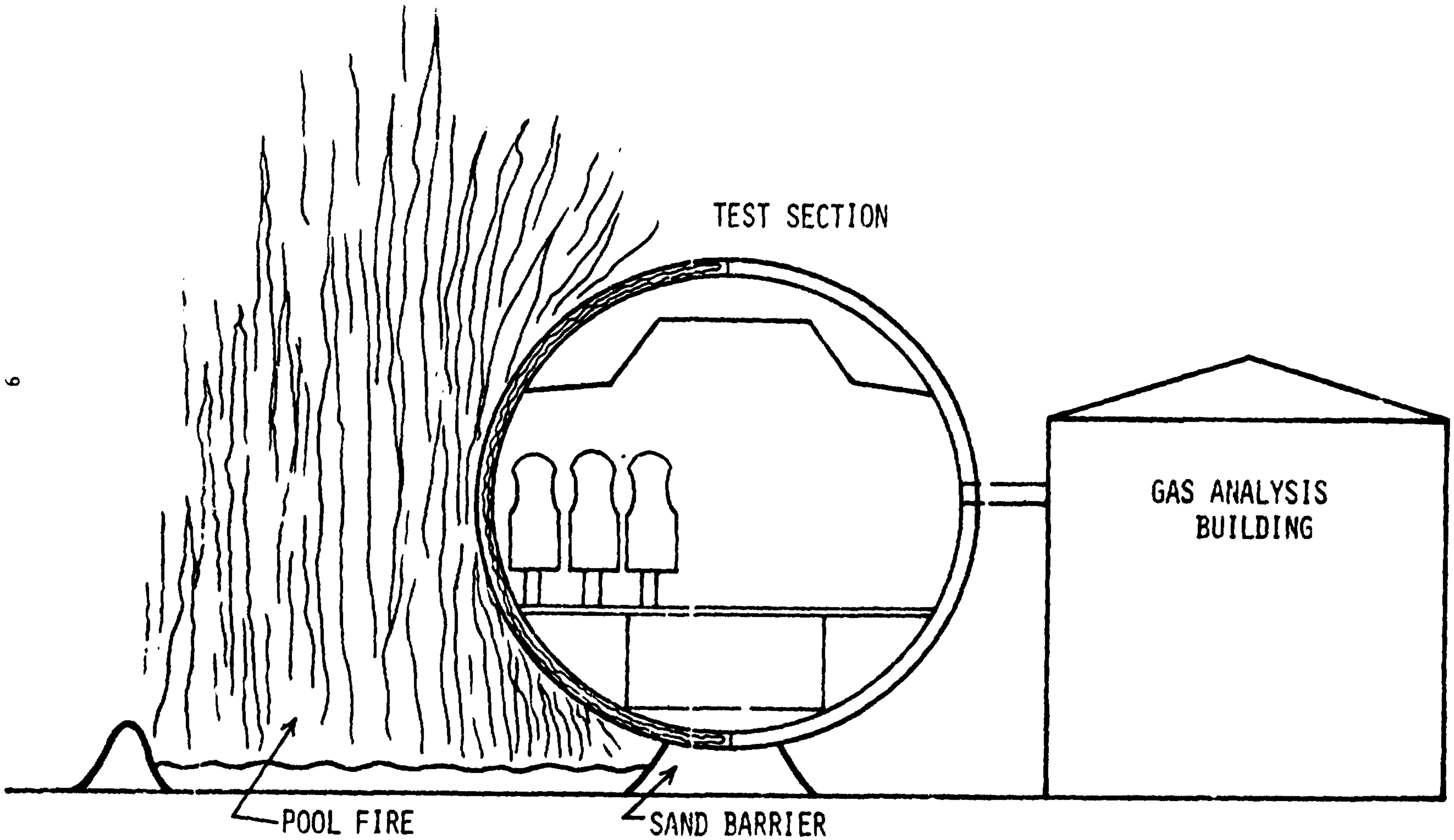
- FABRICATION AND ASSEMBLY OF COMPLETE PANEL BY AIR RESEARCH
- SELECT POOL SIZE FROM PREVIOUS TESTS
- INSTRUMENT AND INSTALL PANEL AT 45° ANGLE
- PROTECT PERIPHERY OF TEST PANEL TO PREVENT FIRE ON BACK SIDE OF PANEL
- MAXIMUM OF THREE CONFIGURATIONS

PHASE III - FULL SCALE TESTS

APPROACH

- REFURBISH 20 FOOT SECTION OF 737 WITH SELECTED MATERIALS (AIR RESEARCH)
- USE EXISTING SITE OF 737 AND GAS ANALYSIS SHACK (NO PERSONNEL IN SHACK DURING TEST)
- PREPARE POOL WITH BANK SAND DIKES ADJACENT TO TEST SECTION (ALPHA CONSTRUCTION)
- BUILD SAND BULKHEAD UNDER CENTER LINE OF FUSELAGE FULL LENGTH TO RESTRICT FIRE TO ONE SIDE OF FUSELAGE (ALPHA CONSTRUCTION)
- PROVIDE PROTECTION TO GAS ANALYSIS SHACK IF INDICATED FROM PHASE I FIRE GEOMETRY (INSULATED BULKHEAD, WATER SPRAY, FIRE DEPARTMENT STANDBY)

FULL SCALE TEST CONFIGURATION



FULL SCALE TEST SCHEDULE

- FULL SCALE TEST OBJECTIVES SUGGEST SECOND TEST (LOW SMOKE, TEMPS > 5 MIN, VERSUS FIRE IN CABIN OPENING)

- FIRST FULL SCALE TEST SCHEDULED FOR SEPTEMBER 1980

- REFURBISHMENT FOR SECOND TEST WOULD TAKE AN ADDITIONAL 6 MONTHS (COMPATIBLE W/SCHEDULE PRESENTED 4/78)

- PACING ITEM IS INITIATION OF AIR RESEARCH CONTRACT

SCHEDULE RESPONSIBILITY ____________

STATUS RESPONSIBILITY ____________

MILESTONE SCHEDULE

RTOP NO.: 510

RTOP TITLE: FIRE RESISTANT MATERIALS ENG.

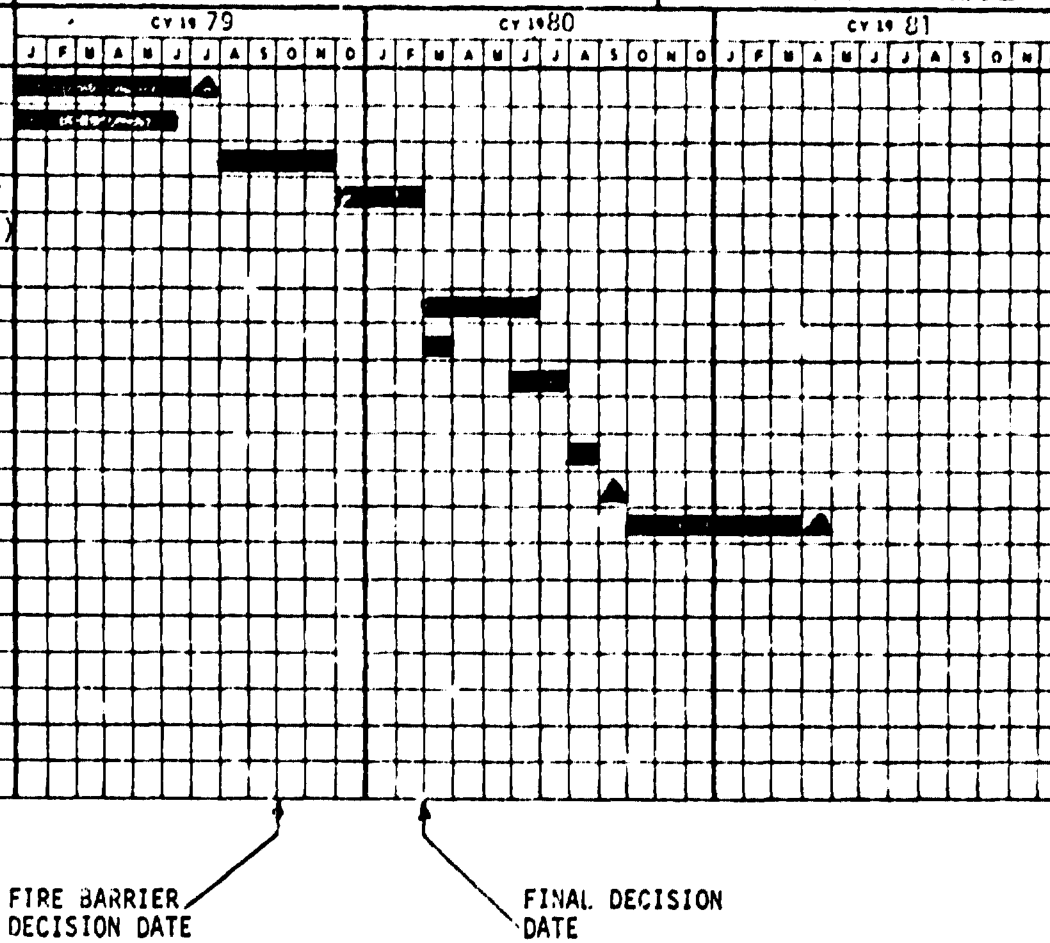
4 LEVEL

ORIGINAL SCHEDULE APPROVAL ______ (DATE)

LAST SCHEDULE CHANGE ______ (DATE) (NO.) (INITIALS)

STATUS AS OF ______ (DATE) (INITIALS)

	MILESTONES
1	AIR RESEARCH CONTRACT
2	POOL FIRE TESTS (PHASE I)
3	FABRICATION OF TEST PANELS
4	ASSEMBLE, INSTRUMENT, AND TEST
5	OF 10' X 10' PANELS (PHASE II)
6	REFURBISH 737 (AIR RESEARCH)
7	-PROCURFMENT OF GFE
8	-PROCUREMENT OF CFE
9	-FABRICATION AND INSTALL
10	FULL SCALE TEST (1)
11	-INSTRUMENT & CHECKOUT
12	-CONDUCT TEST (PHASE III)
13	SECOND FULL SCALE TEST (DOOR
14	OPEN) (PHASE III)
15	
16	
17	
18	
19	
20	



NOTES:

RESEARCH AND TECHNOLOGY OBJECTIVE AND PLAN (CONTINUATION SHEET)

RTOP SCHEDULE

R T NUMBER:

TITLE:

CURRENT NUMBER/CODE:

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R. BRICKER

SEAT TEST PROGRAM

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OUTLINE

- OBJECTIVES
- TEST CONFIGURATIONS AND DATA ACQUIRED
- MATERIAL TEST RESULTS
- SEAT TEST RESULTS
- CONCLUSIONS

OBJECTIVES

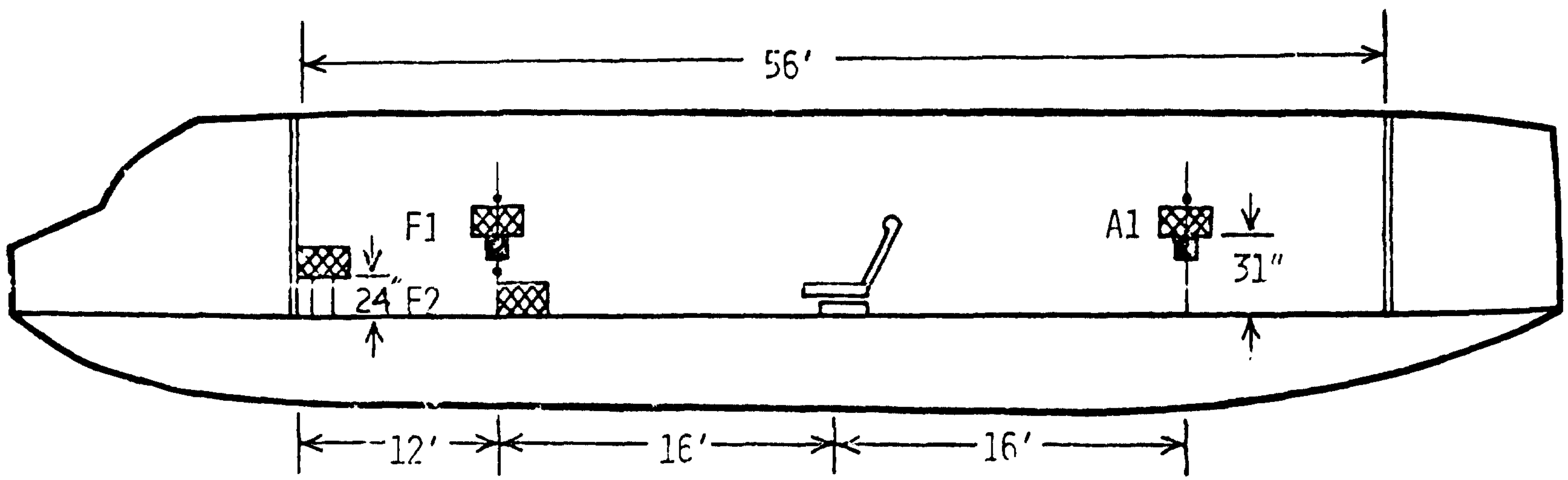
- EVALUATE SEVERITY OF NEWSPAPER IGNITION SOURCE WITH CONTEMPORARY SEATS
  - DETERMINE WEIGHT LOSS AND VISUAL DAMAGE
  - DETERMINE IF IGNITION SOURCE IS SEVERE ENOUGH TO SHOW IMPROVEMENT WITH NEW MATERIAL CONFIGURATIONS
- COMPARE DAMAGE WITH JET A-1 IGNITION SOURCE
- DETERMINE IF MATERIALS FOR SEAT TESTS PASS FAR 25 AND OBTAIN LOI

TEST CONFIGURATIONS

- TESTS CONDUCTED IN STANDARD BODY FUSELAGE WITH IN FLIGHT VENTILATION
- TEST 1
  - NEWSPAPER TENTED ON CENTER SEAT OF THREE UNMODIFIED SEATS
  - NEWSPAPER IGNITED WITH MATCHES
- TEST 2
  - NEWSPAPER TENTED ON CENTER SEAT
  - ARMRESTS REMOVED
  - LEFT SEAT MOVED ADJACENT TO CENTER SEAT
  - NEWSPAPER IGNITED WITH HOT COIL
- TEST 3
  - ARMRESTS REMOVED
  - LEFT SEAT MOVED ADJACENT TO CENTER SEAT
  - 1 LITER OF JET A-1 IN 1 X 1 FOOT PAN UNDER CENTER SEAT
  - FUEL IGNITED WITH PROPANE BURNER

737 TEST SECTION

- VOLUME - 3920 FT^3
- VENTILATION RATE - 1500 CFM



DATA ACQUIRED

- SEATS SUSPENDED FROM LOAD CELL FOR WEIGHT LOSS DURING TEST
- SEAT WEIGHED PRE- AND POST-TEST
- STILL PHOTOS BEFORE AND AFTER
- THREE REAL TIME MOVIE CAMERAS
- ONE VIDEO MONITOR (TAPED)
- TC'S AND CALORIMETERS IN FUSELAGE
- SIX LOSS OF VISIBILITY MEASUREMENTS
- GAS ANALYSIS (O_2, CO, CO_2, HYDROCARBONS, HCN, HCL, AND HF)

SEAT MATERIAL TEST RESULTS

- LOI
  - CUSHION FOAM - 26
  - WOOL BLEND UPHOLSTERY - 32
  - TWO SEAT CUSHION BACKING MATERIALS - 21 AND 28
- FAR 25
  - UPHOLSTERY AND BACKING MATERIALS PASS
  - CUSHION FOAM COATED SPECIMENS FAIL
  - UNCOATED FOAM PASSES DUE TO MELTING AND RECEDING FROM FLAME

SEAT TEST RESULTS

TEST 1

- IGNITION SOURCE SLOW TO DEVELOP (TOO TIGHTLY COMPRESSED)
- AT ~5 MINUTES ARMREST IGNITED
- ARMREST IGNITED ADJACENT SEAT
- CENTER SEAT MATERIALS ~90 PERCENT BURNED
- ADJACENT SEAT ~70 PERCENT BURNED
- TOTAL MATERIAL WT. LOSS 10.5 LBS.
- TEMPERATURES IN CABIN FROM AMBIENT TO 350°F
- NO SIGNIFICANT HEAT FLUXES
- MUCH SMOKE-LOSS OF VISIBILITY AFTER SEAT INVOLVEMENT
- HIGH CO, HCN AT 10 MIN.

SEAT TEST RESULTS

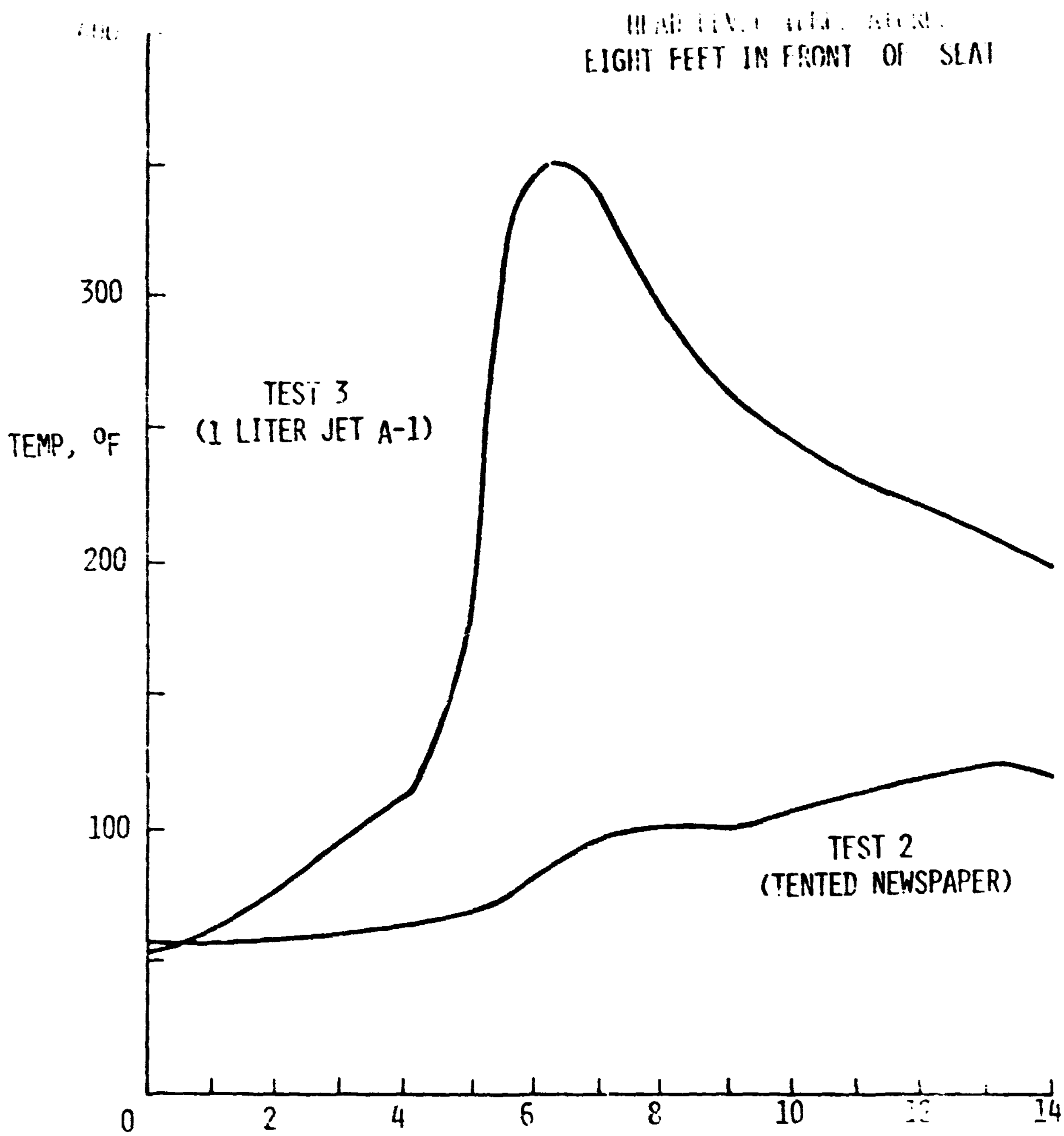
TEST 2

- MORE RAPID DEVELOPMENT OF NEWSPAPER IGNITION SOURCE
- CENTER SEAT BACK IGNITED AT ~ 4 MINUTES
- CENTER SEAT MATERIALS ~70 PERCENT DESTROYED
- ADJACENT SEATS NOT IGNITED
- TOTAL MATERIAL WT. LOSS ~7 LBS.
- CABIN TEMPERATURES 80°F TO 240°F
- NO SIGNIFICANT HEAT FLUXES
- CONSIDERABLE SMOKE-LOSS OF VISIBILITY AFTER SEAT INVOLVEMENT
- HIGH HCN, CO AT 12 AND 15 MIN.

SEAT TEST RESULTS

TEST 3

- MORE RAPID INVOLVEMENT OF SEATS THAN WITH NEWSPAPER
- EXTENSIVE PROPAGATION TO ADJACENT SEATS (~ 90 PERCENT OF ALL 3 SEATS DESTROYED
- WEIGHT LOSS ~31.4 LBS. (> 3 TIMES THAT WITH NEWSPAPERS)
- CABIN TEMPERATURES 200 TO 950°F
- BURNING AND SMOKE OVER LONGER PERIOD (15 MIN.)
- HIGH CO, HCN, AND HCL LEVELS


EIGHT FEET IN FRONT OF SLAT
TEMP, °F
300
200
100
0
2
4
6
8
10
14
TEST 3
(1 LITER JET A-1)
TEST 2
(TENTED NEWSPAPER)

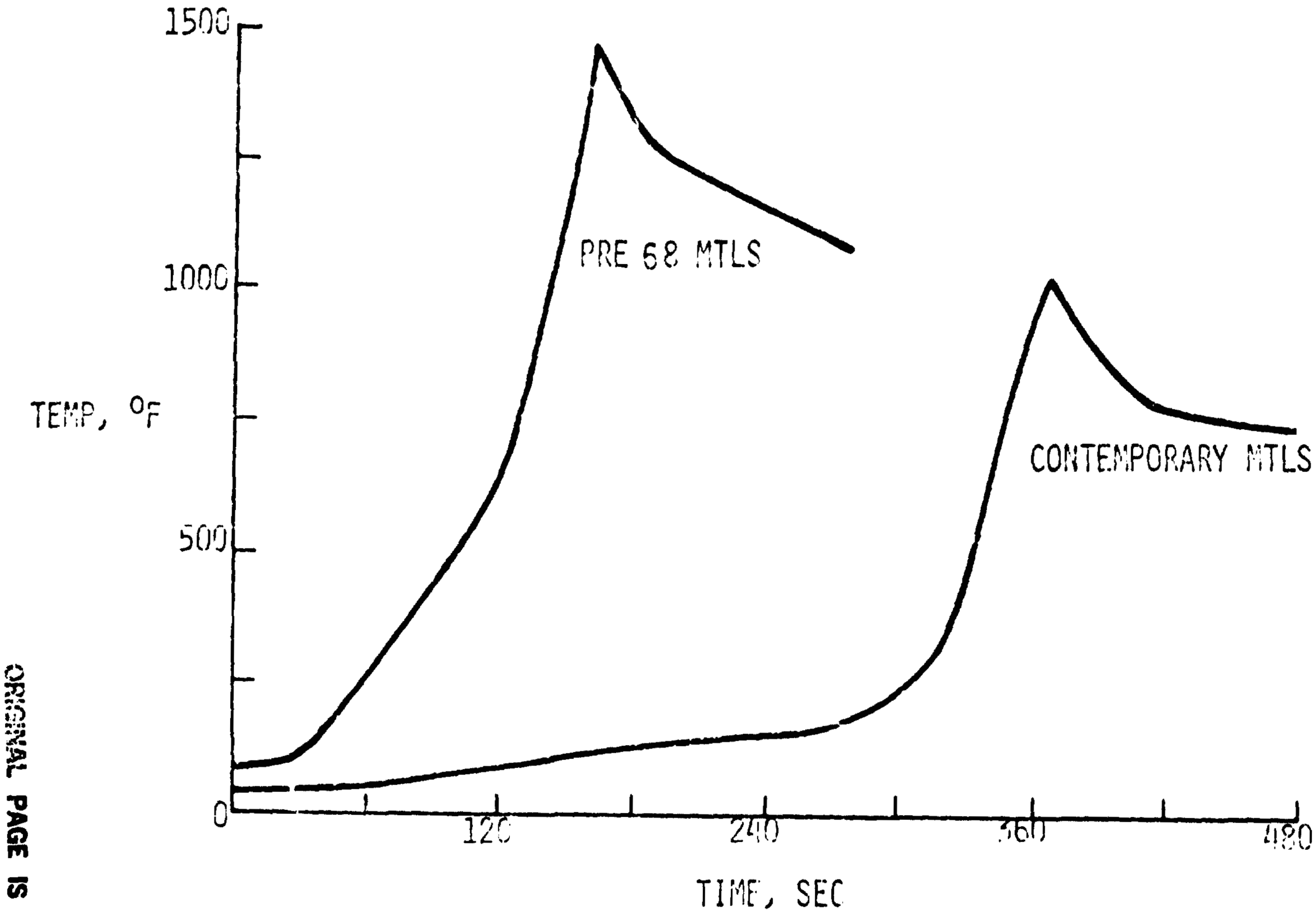
GAS ANALYSIS RESULTS

(5 FEET HIGH ALONG CENTER LINE)

TEST NR AND IGNITION SOURCE		MAXIMUM GAS LEVELS					
		CO		HCN		HCL	
		8 FT FWD	16 FT AFT	8 FT FWD	16 FT AFT	8 FT FWD	16 FT AFT
1 NEWSPAPER WITH ARMRESTS	PPM	1340	2294	108	78	522	330
	T	9.5	9.5	9.5	9.5	9.5	9.5
2 NEWSPAPER WITHOUT ARMRESTS	PPM	1126	712	102	25	414	23
	T	15	13	12.5	11.5	11.5	15.5
3 JET A-1 FUEL	PPM	2232	3097 3596*	330	102	880	192
	T	6.5	6.5	6.5	7.5	12.5	15.5

*EIGHT FEET AFT — 20 INCHES HIGH AT 5.5 MIN

COMPARISON OF CONTEMPORARY AND PRE 68 MTLS



CONCLUSIONS

- ARMRESTS OF THE SEATS TESTED HIGHLY FLAMMABLE
- NEWSPAPER IGNITION SOURCE WILL IGNITE SEAT IT IS ON (NO SIGNIFICANT PROPAGATION TO ADJACENT SEATS)
- FUEL PAN FIRE UNDER SEAT PROPAGATES TO AND DESTROYS ADJACENT SEATS
- SEATS TESTED NOT SIGNIFICANTLY BETTER THAN WITH PRE-68 MTLS (BASED ON FUEL PAN TESTS BY FAA, AIA, AND JSC)
- NEWSPAPER IGNITION SOURCE WILL BE MARGINAL IN SHOWING SIGNIFICANT DIFFERENCES WITH IMPROVED SEAT MATERIALS

D3

N79-31169

D. RUSSO

RECENT ADVANCES IN MATERIALS TOXICOLOGY

OUTLINE

- OVERVIEW OF JSC FIRE TOXICOLOGY PROGRAM
  - PRINCIPAL OBJECTIVE
  - APPROACH
- LABORATORY METHODS OF ASSESSING PYROLYSIS PRODUCT TOXICITY
  - EXPERIMENT 1: COMPARISON OF TEST END POINTS
  - EXPERIMENT 2: EVALUATION OF OPERANT TECHNIQUES
- COMPARISON OF FULL-SCALE AND LABORATORY TOXICITY TESTS
  - EXPERIMENT 3: PRELIMINARY WORK
- FUTURE RESEARCH PLANS AT JSC

OVERVIEW OF JSC FIRE TOXICOLOGY PROGRAM

- PRINCIPAL PROGRAM OBJECTIVE: ASSIST IN THE DEVELOPMENT OF TOXICOLOGIC SCREENING PROCEDURES

- PROGRAM APPROACH: RESEARCH IN TWO AREAS

  - LABORATORY METHODS FOR ASSESSING PYROLYSIS PRODUCT TOXICITY

  - COMPARISON OF FULL-SCALE AND LABORATORY TOXICITY TESTS

- COMPARATIVE NATURE OF EXPERIMENTS

LABORATORY METHODS OF ASSESSING PYROLYSIS PRODUCT TOXICITY

- EXPERIMENT 1: COMPARISON OF BEHAVIORAL END POINTS
  - PURPOSE: DO TEST BEHAVIORS VARY IN SUSCEPTIBLITY TO TOXIC INCAPACITATION?
  - METHOD:
  - RESULT:
  - CONCLUSION: TUF IS A FUNCTION OF MECHANISM OF INCAPECITATION AND BEHAVIORAL REQUIREMENTS OF TEST.

LABORATORY METHODS OF ASSESSING PYROLYSIS PRODUCT TOXICITY

- EXPERIMENT 2: EMPLOY OPERANT TECHNIQUES TO ASSESS THE TOXICITY OF 2 POLYURETHAN FOAMS.
  - PURPOSE: EVALUATE OPERANT TECHNIQUES FOR TOXICOLOGICAL SCREENING.
  - METHOD:
  - RESULTS: 1. CO ANALYSIS
    2. CUMULATIVE RECORDS
    3. STATISTICAL SUMMARY

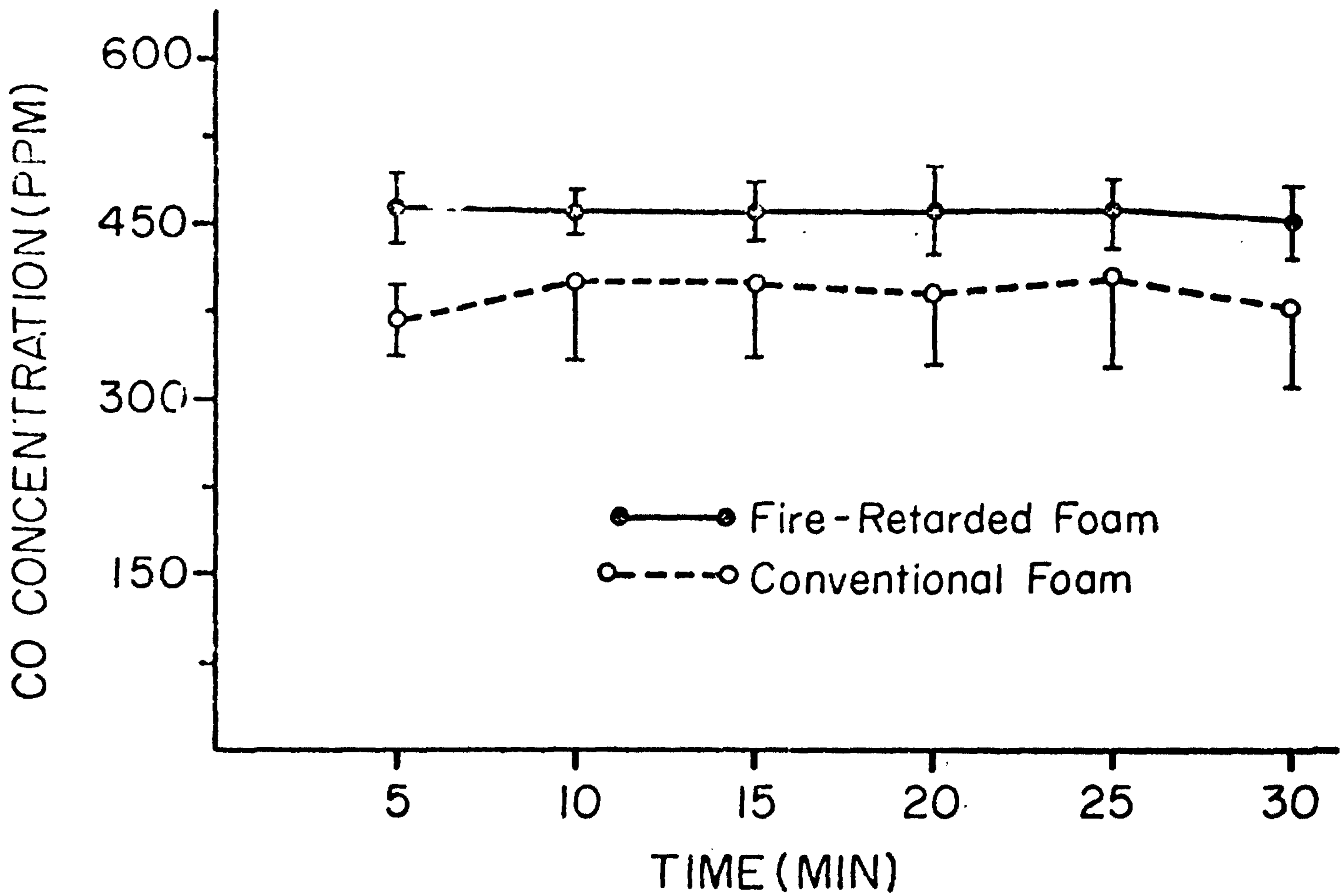


FIGURE 1. Mean CO Concentration ± 1 S.E. as a Function of Test Time.

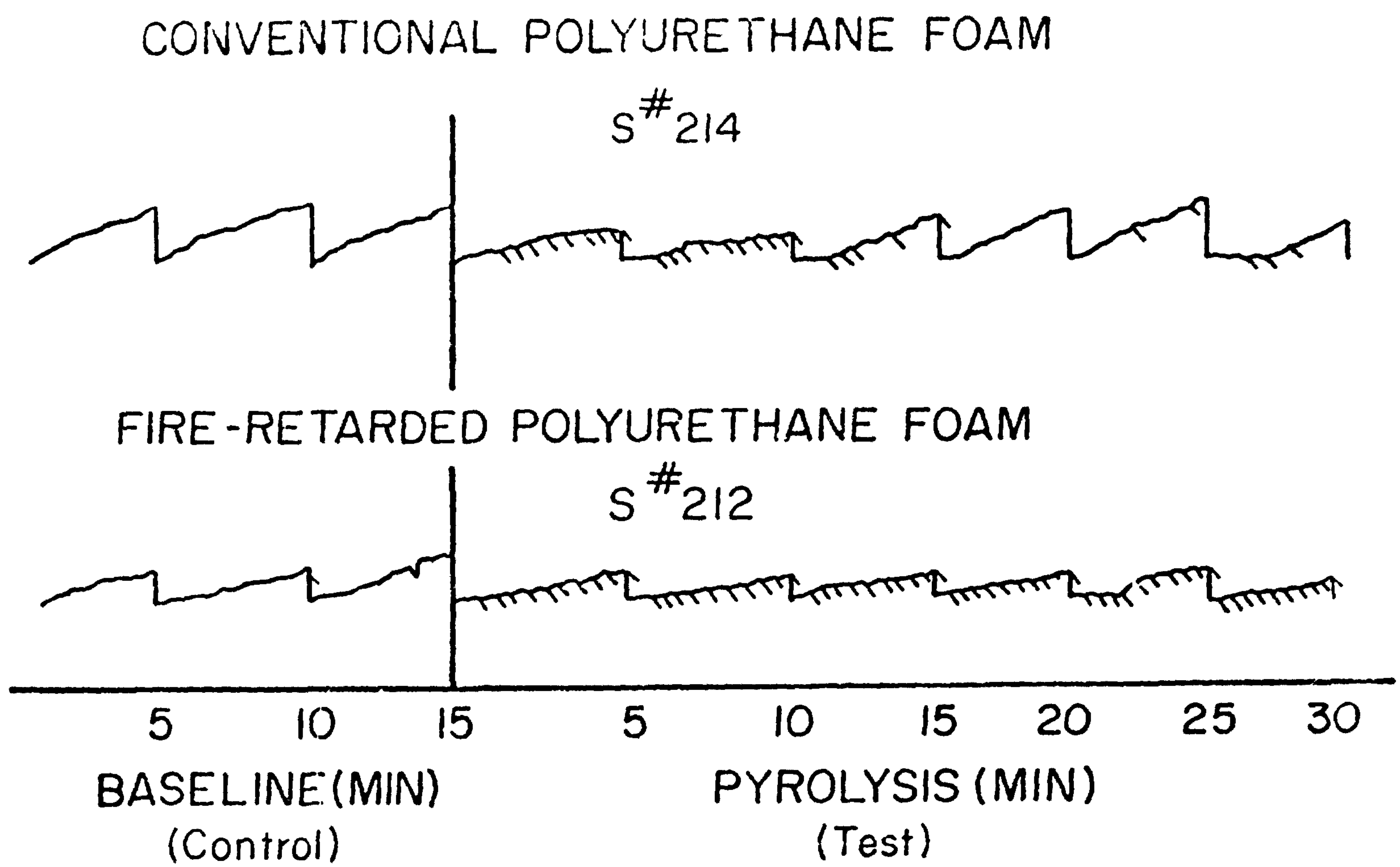


FIGURE 2. Cumulative Records Showing Effect of Foam Pyrolysis on Signalled (Discriminative) Shock Avoidance. (Upward Displacement of Line Indicates Bar Response and Downward Slash Represents Shock Occurence.)

TABLE I. Pyrolysis-Induced Changes in Operant Performance. Each Cell Represents The Results of a Paired T-Test. NS = No Significant Change ($p > .05$), ↑ = Significant Increase ($p < .05$), ↓ = Significant Decrease ($p < .05$)

UNSIGNALLED (SIDMAN) AVOIDANCE														
	FIRE-RETARDED FOAM							CONVENTIONAL FOAM						
	TEST MIN.							TEST MIN.						
RATES (PER MIN)	5	10	15	20	25	30	TOT	5	10	15	20	25	30	TOT
AVOIDANCE	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
ESCAPE	NS	↑	NS	NS	NS	NS	NS	NS	↑	↑	NS	NS	↑	NS
NO. OF UNESCAPED SHOCKS	↑	↑	NS	NS	NS	NS	↑	NS	NS	NS	NS	NS	NS	NS
% ESCAPE	↓	↓	NS	NS	NS	NS	↓	NS	NS	NS	NS	NS	NS	NS
SHOCK TIME	↑	↑	↑	NS	NS	↑	↑	↑	↑	NS	NS	NS	NS	NS
SIGNALLED (DISCRMINATIVE) AVOIDANCE														
	TEST MIN.							TEST MIN.						
10 TRIAL BLOCKS	5	10	15	20	2	30	TOT	5	IC	15	20	25	30	TOT
AVOIDANCE	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
ESCAPE	NS	NS	NS	NS	NS	↑	NS	NS	NS	NS	NS	↑	↑	↑
NO. OF UNESCAPED SHOCKS	NS	NS	NS	↑	↑	↑	↑	NS	↑	NS	NS	NS	NS	NS
SHOCK TIME	↑	↑	↑	↑	↑	↑	↑	↑	↑	NS	NS	NS	NS	NS

CONCLUSIONS FROM EXPERIMENT 2

DISADVANTAGES:

1. TRAINING TIME
2. DATA BASE ESTABLISHED WITH ALTERNATIVE TECHNIQUES

ADVANTAGES:

1. REMOTE MONITORING OF BEHAVIOR
2. CONTINUOUS MONITORING OF BEHAVIORAL CHANGES
3. QUANTIFY BEHAVIORAL CHANGES
4. CORRELATION WITH GAS CONCENTRATIONS

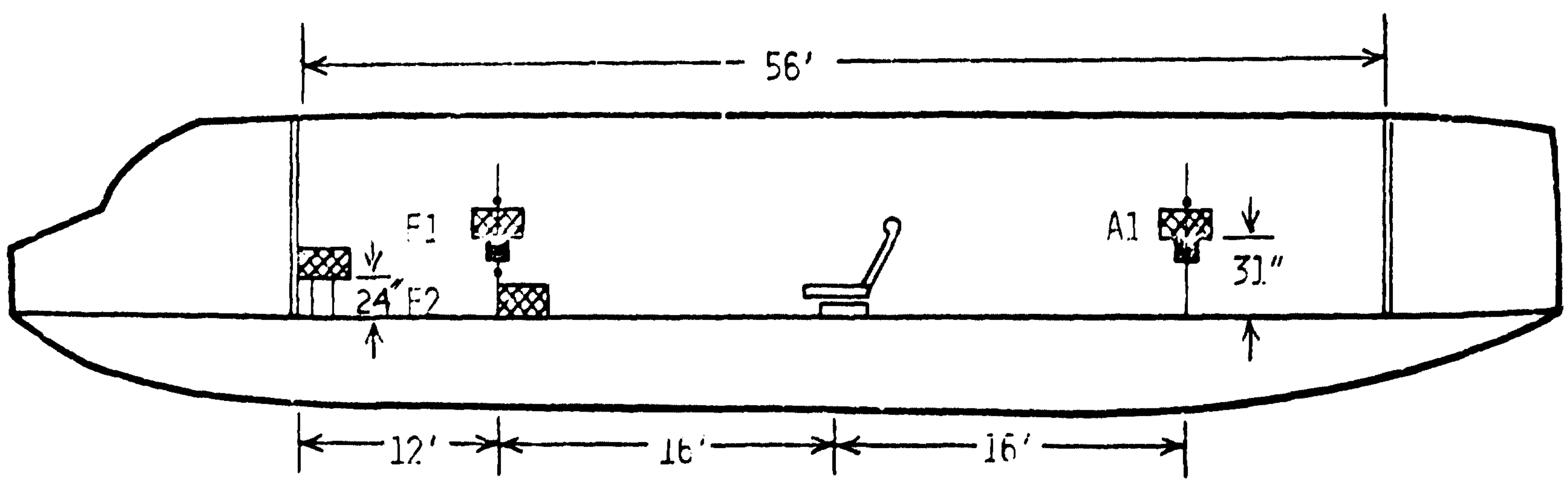
COMPARISON OF FULL-SCALE AND LABORATORY TOXICITY TESTS

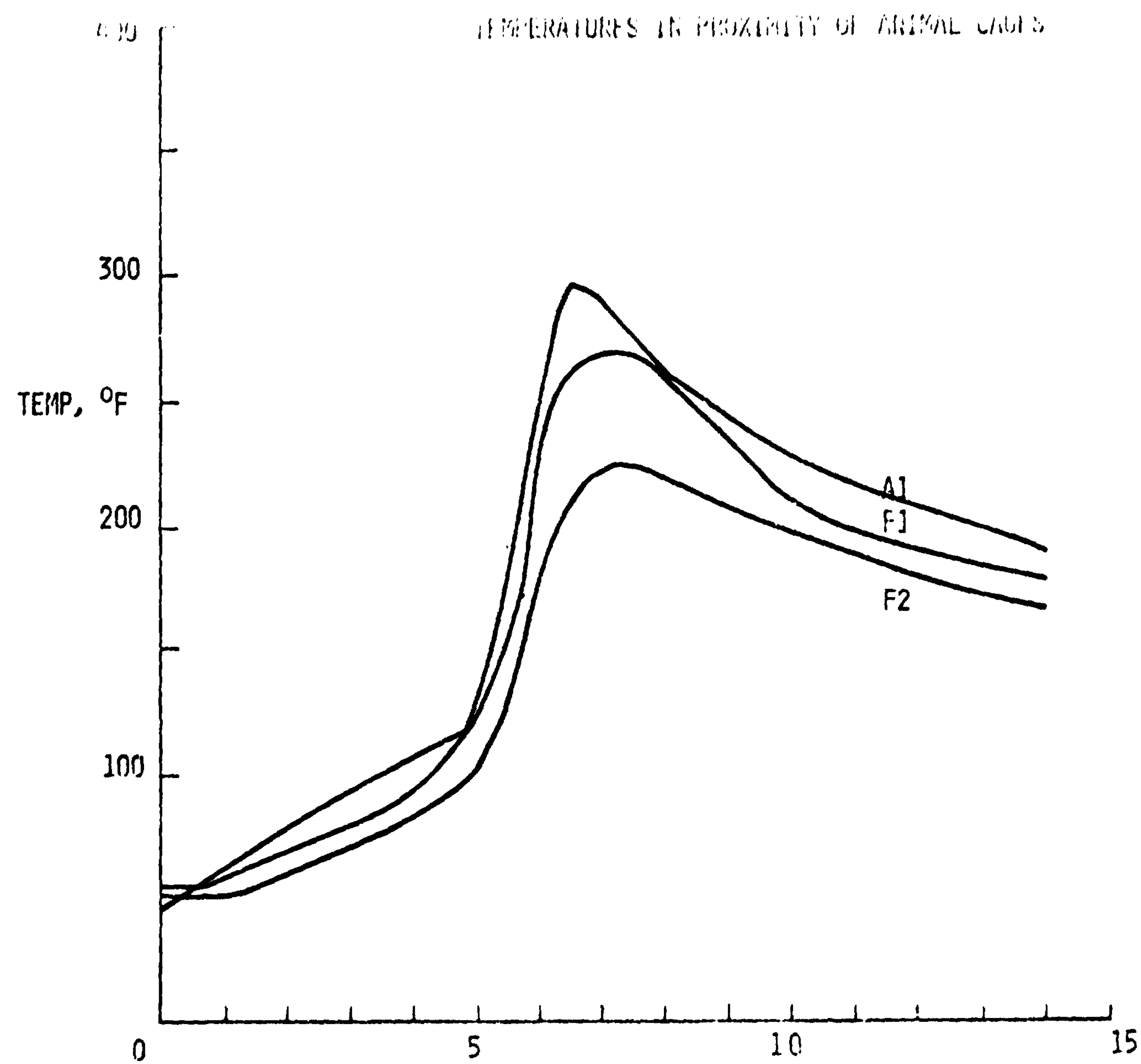
EXPERIMENT 3: PRELIMINARY WORK

- PURPOSE: DETERMINE ANIMAL SURVIVABILITY IN FULL-SCALE TESTS
- METHOD:
- RESULTS: 1. TEMPERATURE PROFILES
  2. CO AND HCN ANALYSES
  3. SURVIVAL AND COHB ANALYSES

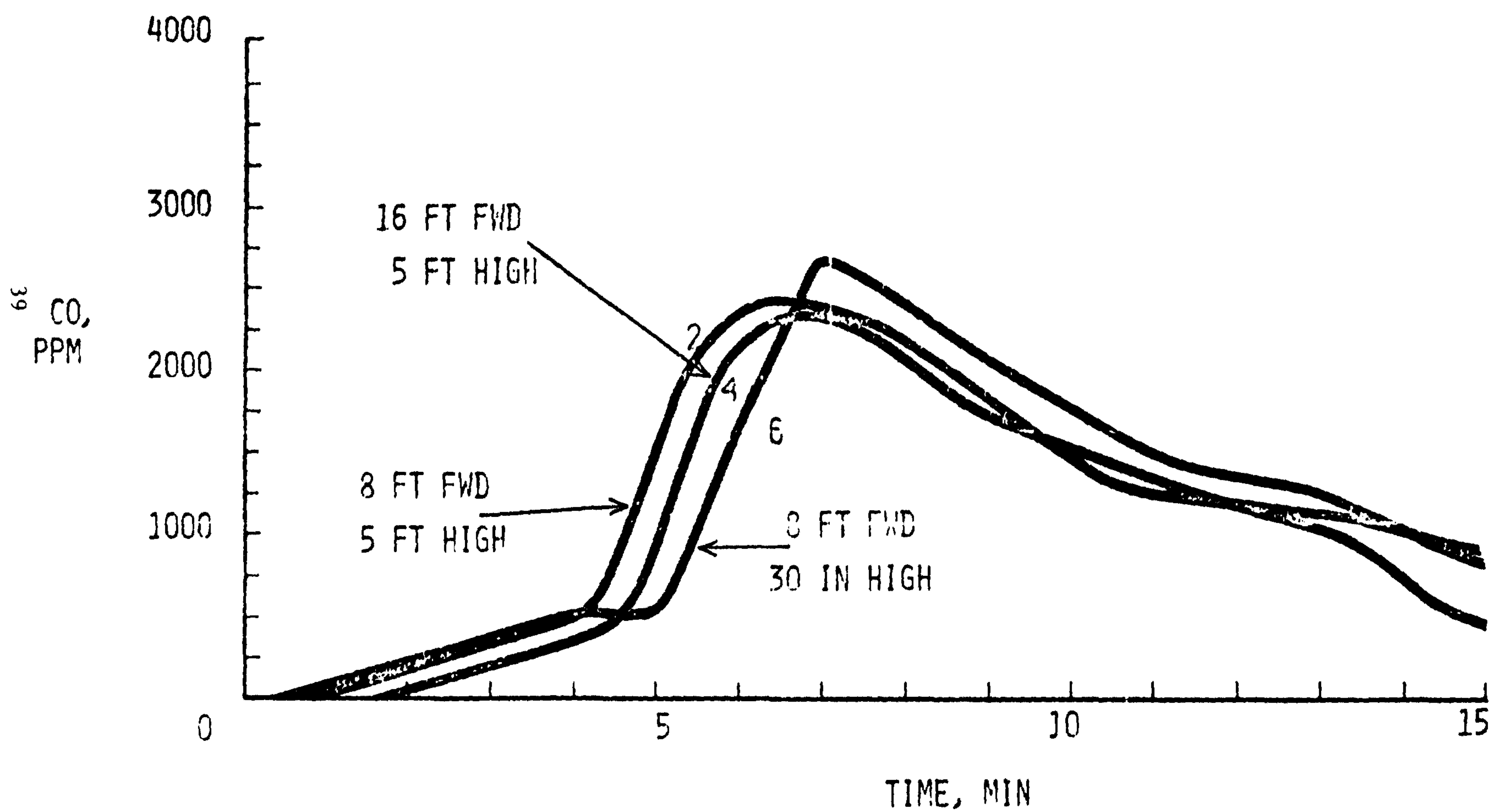
737 TEST SECTION

- VOLUME - 3920 FT^3
- VENTILATION RATE - 1500 CFM

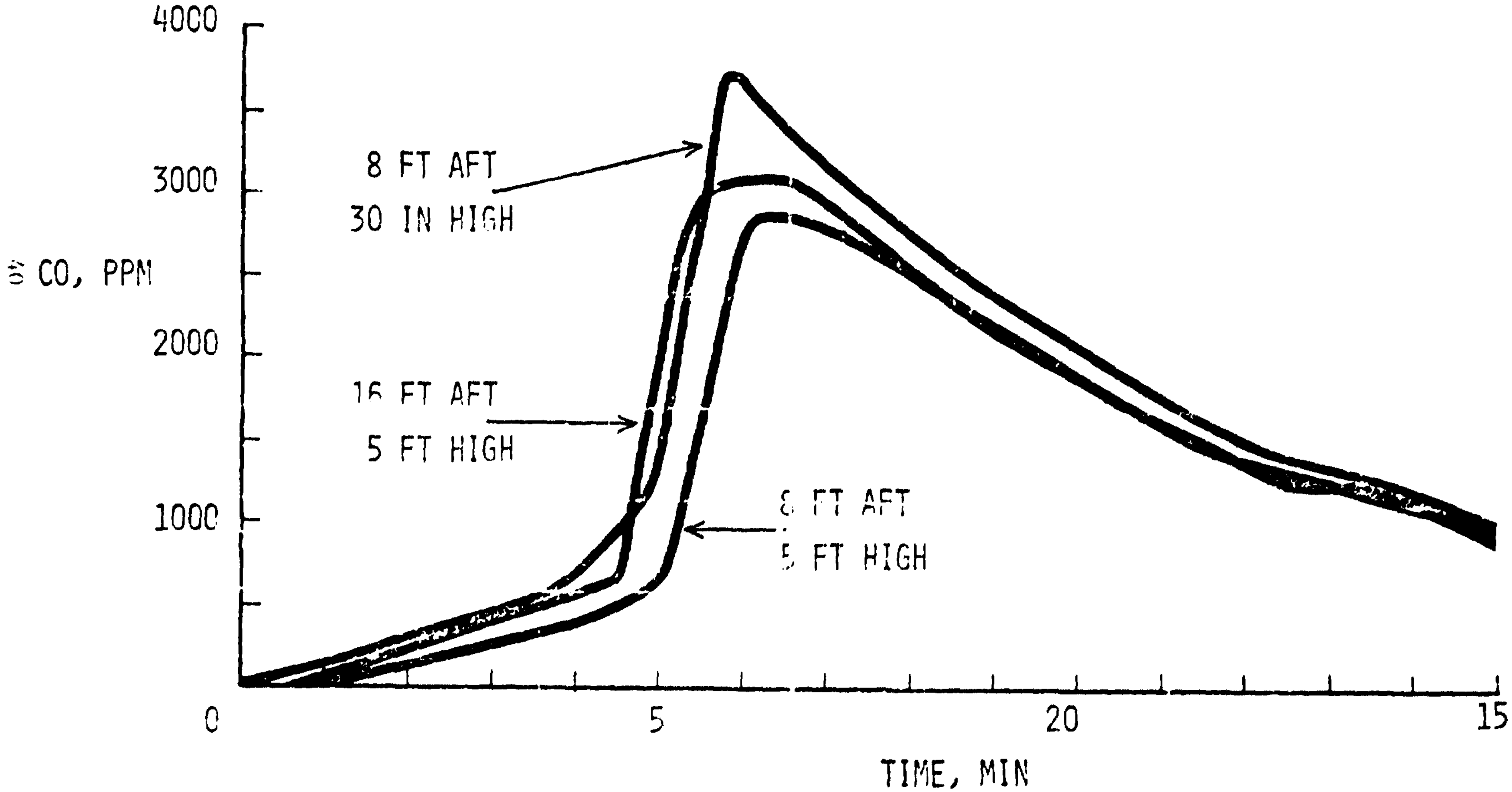


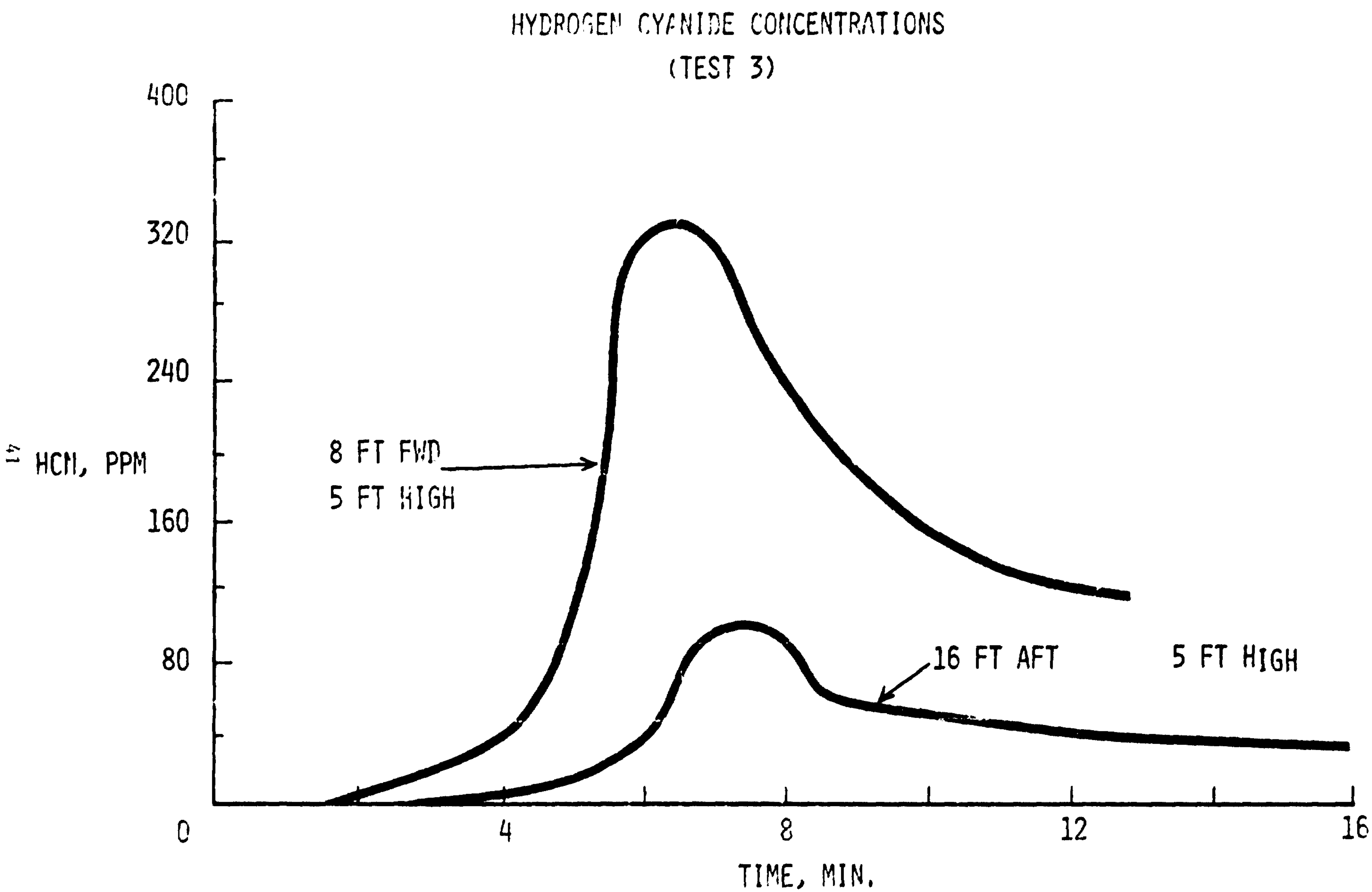

TEMPERATURES IN PROXIMITY OF ANIMAL CAGES
300
200
100
TEMP, °F
A1
F1
F2
0
5
10
15

CARBON MONOXIDE CONCENTRATIONS



CARBON MONOXIDE CONCENTRATION
(TEST 3)





HYDROGEN CYANIDE CONCENTRATIONS
(TEST 3)
400
320
240
160
80
0
HCN, PPM
8 FT FWD
5 FT HIGH
16 FT AFT
5 FT HIGH
4
8
12
16
TIME, MIN.

CONCLUSIONS FROM EXPERIMENT 3

1. FULL-SCALE VARIATIONS IN TEMPERATURE AND GAS CONCENTRATIONS

2. TOXICITY ASSESSMENTS LIKELY TO VARY

3. STANDARDIZATION AND REFINEMENT OF TECHNIQUES

FUTURE RESEARCH PLANS AT JSC

1. FURTHER COMPARISONS OF LABORATORY METHODS: SEATING MATERIAL TESTS

2. FULL-SCALE TOXICITY TESTS: USE OF DIFFERENT BEHAVIORAL TASKS

3. COMPARISON OF FULL-SCALE AND LABORATORY TOXICITY ASSESSMENTS

4. DELINEATION OF LABORATORY METHODS

D4

N79-31170

D. SUPKIS

STATUS OF CANDIDATE MATERIALS FOR FULL-SCALE TESTS IN THE 737 FUSELAGE

OBJECTIVES

- o INCREASED PASSENGER EVACUATION TIME TO A MINIMUM OF 5 MINUTES FROM COMMERCIAL AIRCRAFT IN CASE OF A FIRE
- o PREVENT AN EXTERNAL FIRE FROM ENTERING CLOSED CABINS FOR 5 MINUTES BY USING FIRE BARRIER MATERIALS IN THE EXTERIOR WALL
- o DEMONSTRATE THAT A CLOSED CABIN WILL NOT REACH 400°F NOR CONTAIN SMOKE OR TOXIC GASES UP TO 400°F
- o PROVE THAT A FIRE NEAR A CABIN OPENING WILL NOT PROPAGATE THROUGH THE CABIN FOR A MINIMUM OF 5 MINUTES

MATERIALS STATUS

- o SEAT CUSHIONS
  - o FIRE BARRIER CONFIGURATION USING PRESENT FOAM (AMES-DAC)
  - o PRESENT POLYIMIDE FOAM MEETS MAJORITY OF SEAT REQUIREMENTS (JSC-SOLAR)
  - o INITIAL EVALUATION OF POLYIMIDE FOAM BY FAIRCHILD-BURNS INDICATED THE FOAM IS FUNCTIONAL IN SEATS
  - o POLYIMIDE FOAM SAMPLES PROVIDED WEBER AIRCRAFT CO. FOR ADDITIONAL EVALUATION

- o UPHOLSTERY AND ASSOCIATED SEAT MATERIALS
  - o WOOL OR WOOL-LEAVIL BLENDS UPHOLSTERY FABRICS CURRENTLY USED ARE SATISFACTORY
  - o DISPOSABLE HEAD REST TOWELS ARE FIRE-RETARDANT AND AVAILABLE
  - o FIRE-RETARDANT COTTON TICKING FOR CUSHIONS MEETS AIRCRAFT REQUIREMENTS AND IS AVAILABLE
  - o FIRE-RETARDANT LEATHER ARM REST AND TRIM MEETS JSC FLAMMABILITY REQUIREMENTS

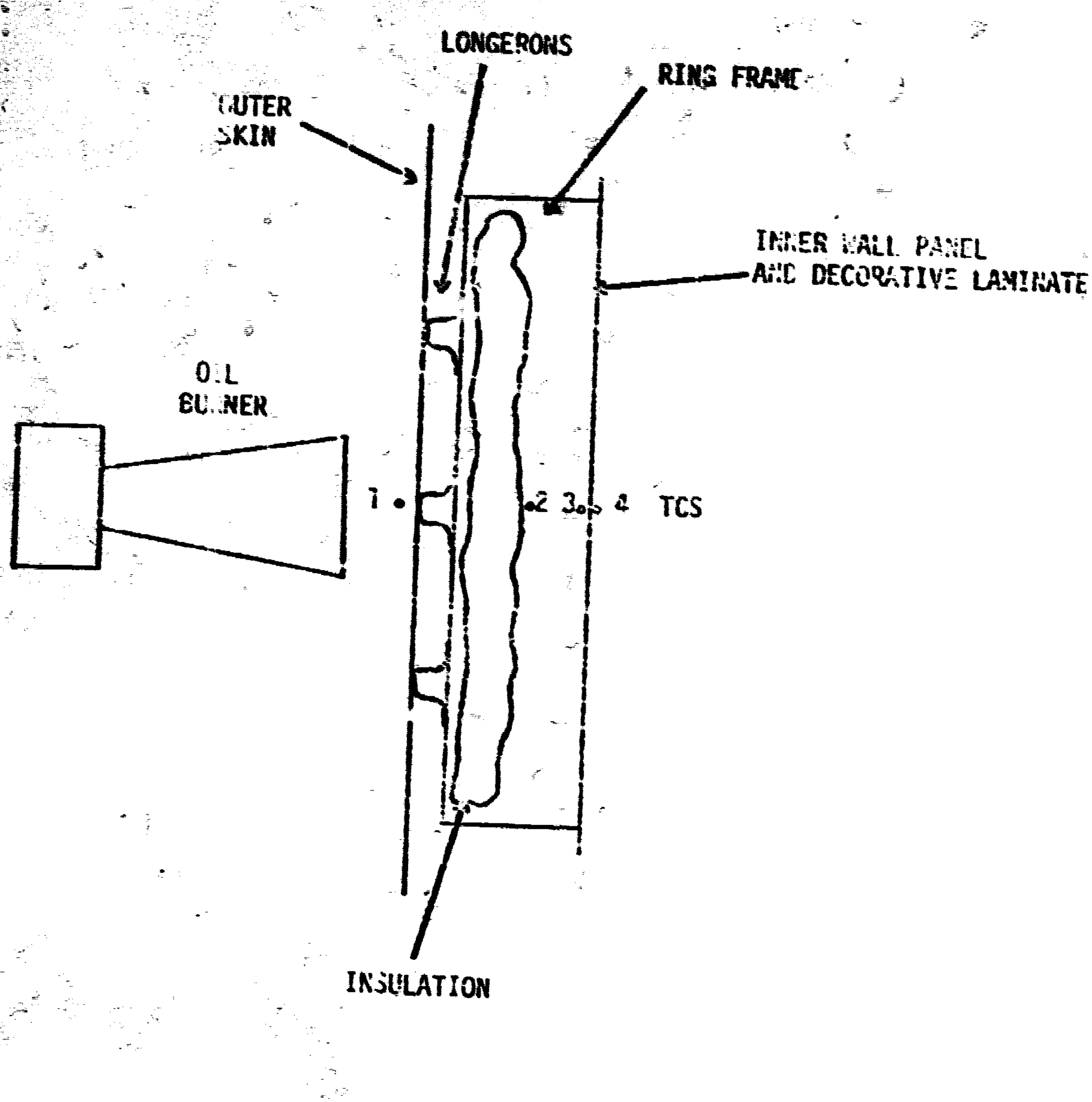
- o WALL AND CEILING PANELS
  - o PHENOLIC/FIBERGLASS LAMINATES AVAILABLE FROM AMES RESEARCH AND LOCKHEED DEVELOPMENT PROGRAMS
  - o EVALUATION OF INITIAL PRODUCTION RUNS OF FLUOREL GLASS WILL RESULT IN AN ADDITIONAL PANEL

- FLOOR PANELS
  - POLYIMIDE FOAM FILLED HONEYCOMB CORE WITH PHENOLIC/GLASS FACE SHEETS MEETS ALL BOEING FLOOR SPECIFICATIONS
  - SAME CONFIGURATION WITHSTOOD BOEING OIL BURNER 15 MINUTES
  - IMPROVED FIRE RETARDANT ADHESIVE NEEDED
- CARPET AND CARPET UNDERLAY
  - NO DEVELOPMENT PROGRAMS ANTICIPATED
  - CURRENT STATE-OF-THE-ART WOOL AND WOOL BLENDS MATERIALS ADEQUATE
  - POLYIMIDE FOAM APPEARS ADEQUATE FOR UNDERLAY
- WINDOWS
  - AMES DEVELOPED WINDOWS CHAR, ELIMINATE RADIANT HEAT AND RESIST BURNTHROUGH FOR 4-5 MINUTES
- CARGO BAY LINERS
  - POLYIMIDE/GLASS AND PHENOLIC/GLASS LAMINATES CURRENTLY A NON-FUNDED DEVELOPMENT EFFORT BY NORDAM AND CIBA-GEIGY
  - SOLAR CAPABLE OF DEVELOPING TECHNOLOGY FOR 50K
- INSULATION BAGGING
  - CERAMIC FIBER SCRIM COMBINED WITH PRESENT ALUMINIZED TEDLAR BAGS TO RETAIN THERMAL-ACOUSTICAL INSULATION
  - CONFIGURATIONS TO BE TESTED IN SEMI-FULL SCALE TESTING IN FUSELAGE CROSS-SECTIONS

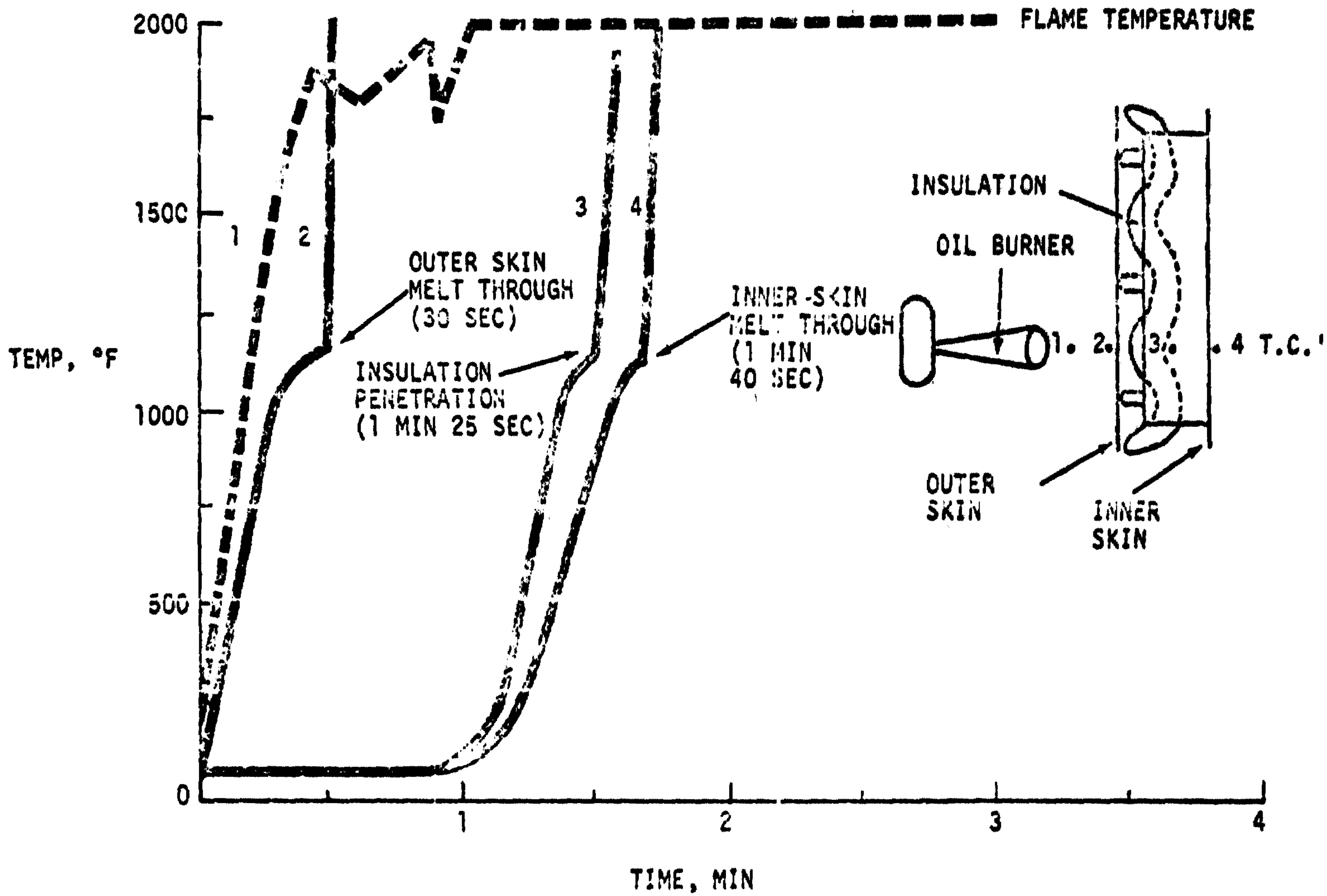
MATERIALS STATUS

- o THERMAL ACOUSTICAL INSULATION
  - o LITAFLEX ASBESTOS FOAM MEETS WEIGHT, TEMPERATURE DIFFERENTIAL, AND FIRE BARRIER PROPERTIES BUT LOW IN ACOUSTICAL ATTENUATION
  - o POLYIMIDE FOAM MEETS WEIGHT REQUIREMENTS ONLY
  - o PREVIOUS POLYIMIDE SAMPLES, TOO LOW IN DENSITY, FAILED TO MEET ACOUSTIC AND FIRE BARRIER REQUIREMENTS
  - o RECENT SAMPLES OF HIGHER DENSITY SHOW IMPROVEMENT IN FIRE BARRIER PROPERTIES
  - o CERAMIC AND CERAMIC-ASBESTOS FOAM UNDER DEVELOPMENT BY RAYBESTOS-MANHATTAN

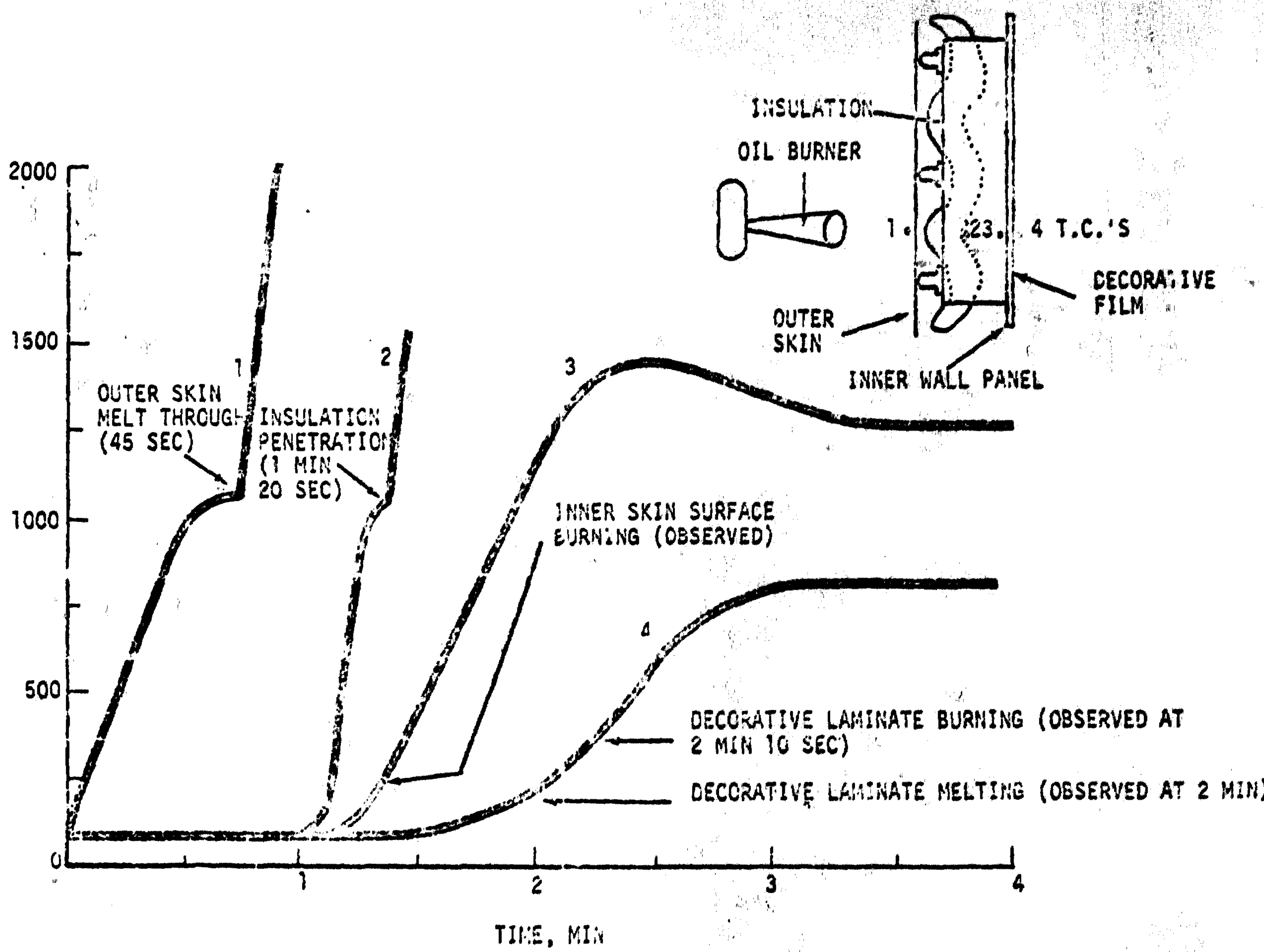
TEST CONFIGURATION



TEMPERATURES DURING TEST OF TYPICAL STANDARD BODY FUSELAGE CROSS SECTION

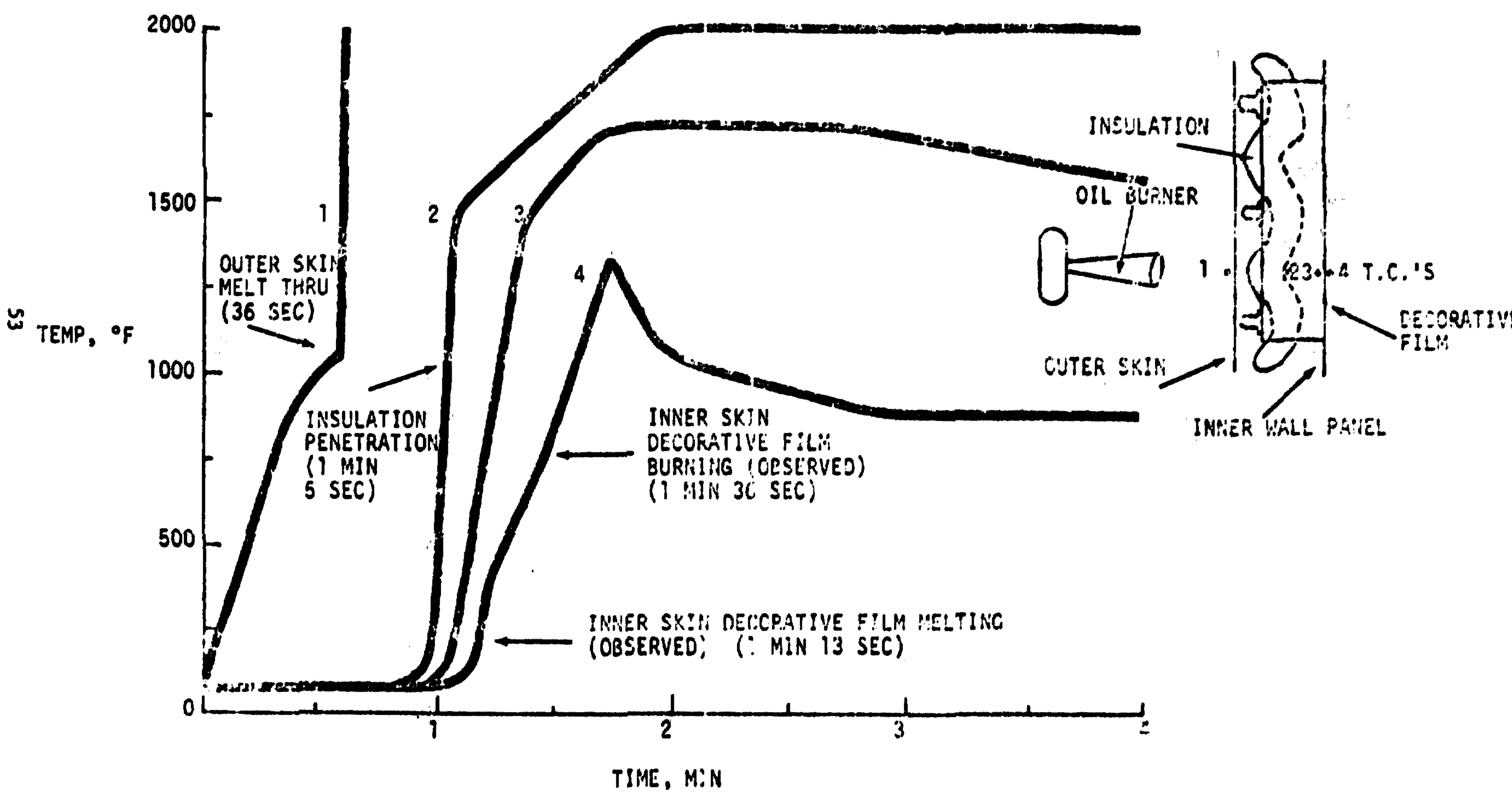


TEMPERATURES DURING TEST OF TYPICAL WIDE BODY FUSELAGE CROSS SECTION



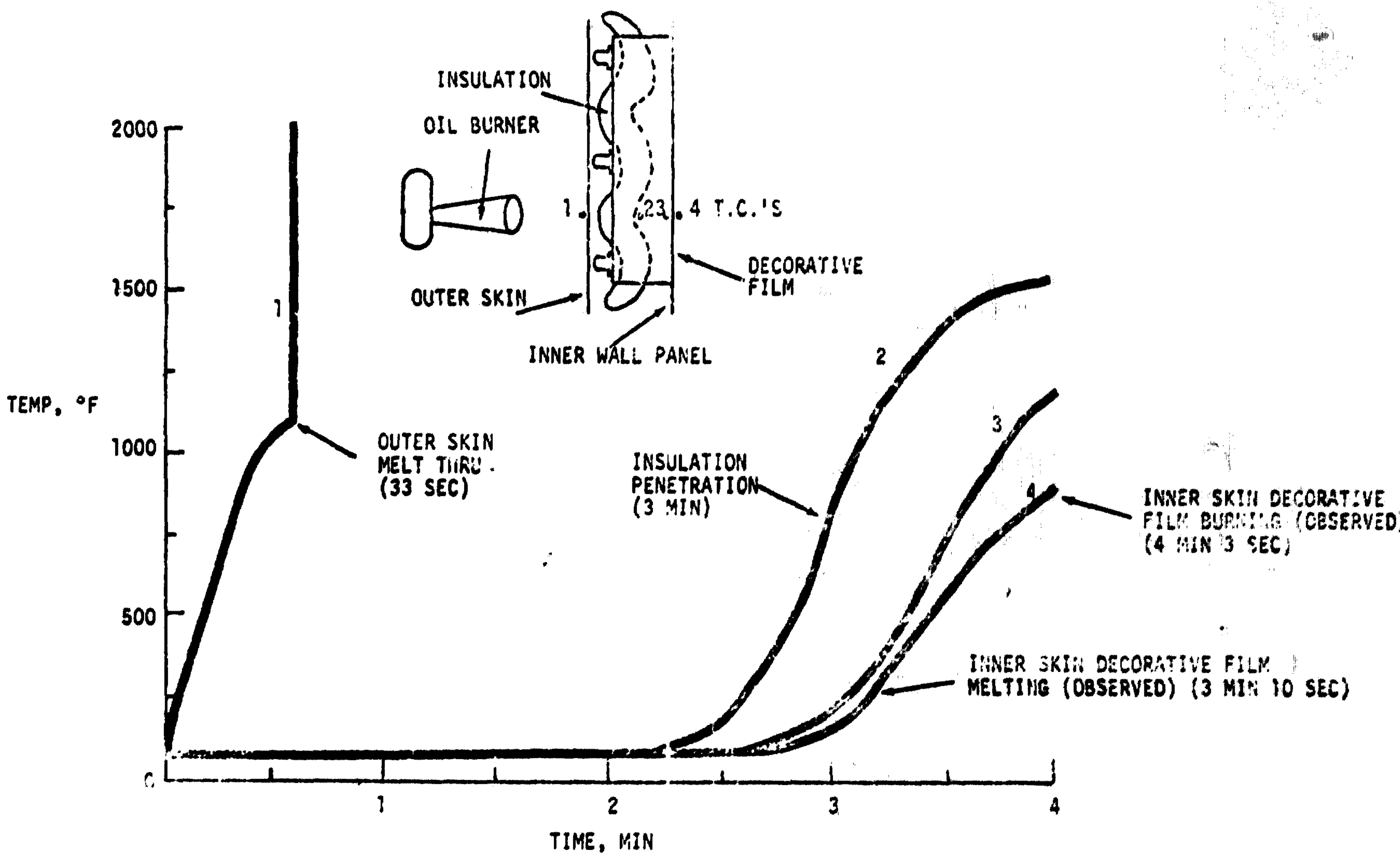
53

TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION
(WITH DECO .040/DECORATIVE FILM INNER SKIN)



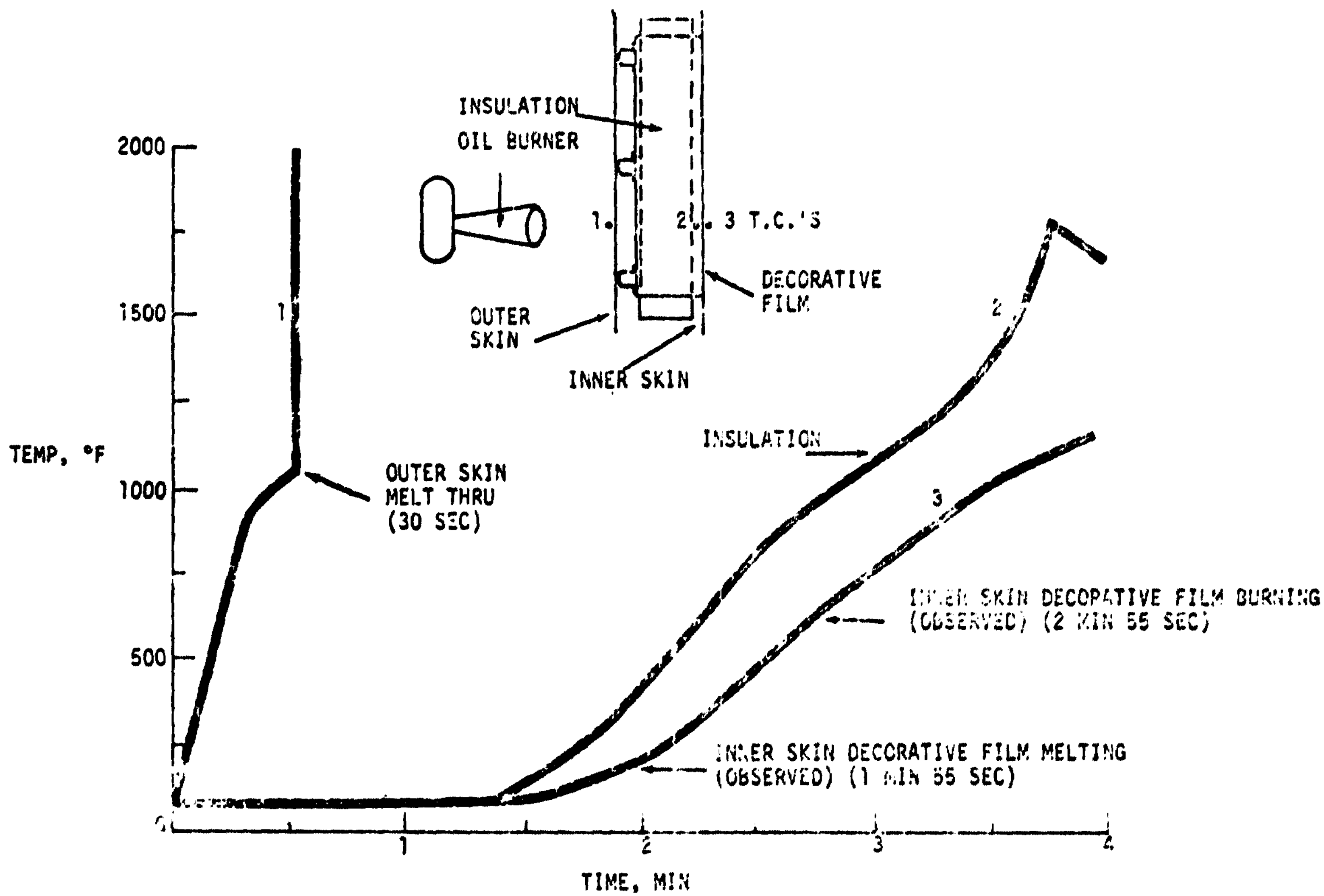
TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION

(WITH .005 GRAFOIL/.(4) 1.5 LB F^3 FIBERGLASS/.005 GRAFOIL/DECO .040 DECORATIVE FILM INNER SKIN)



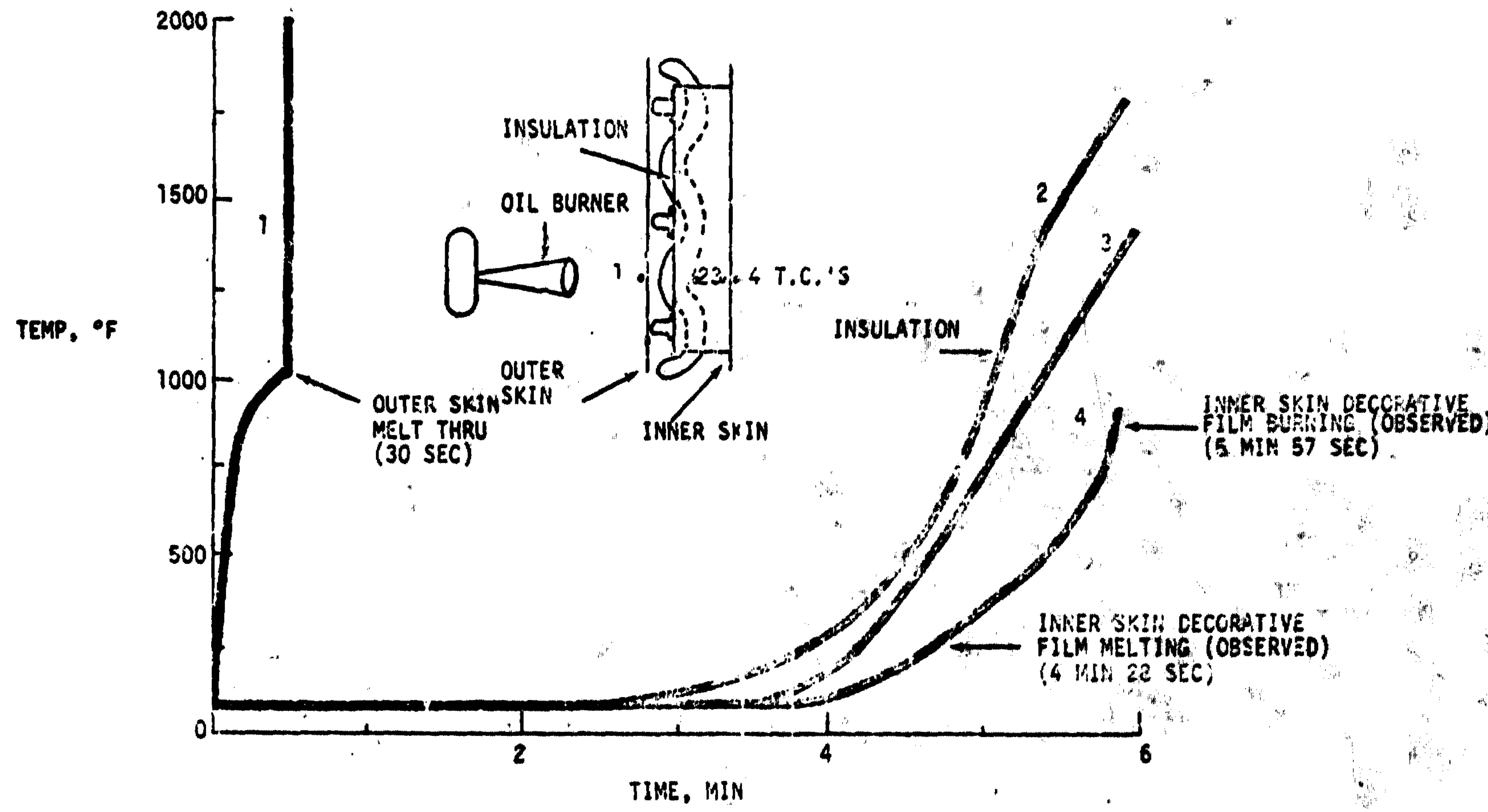
TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION

(WITH .005 GRAFOIL/3" POLYMIDE THERMO/ACOUSTICAL FOAM/.005 GRAFOIL/.040 DECO DECORATIVE FILM INNER SKIN

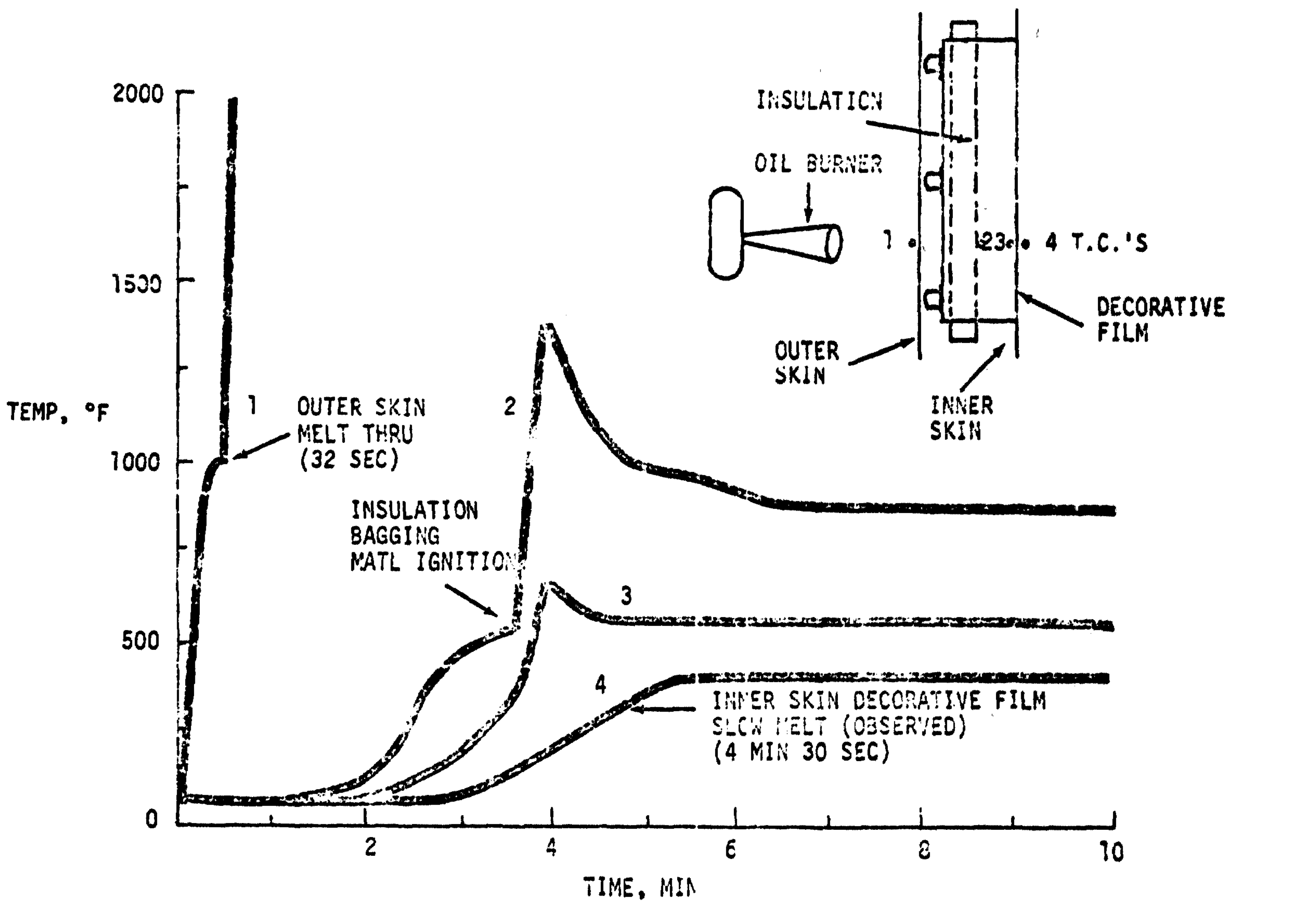


TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION

(WITH .015 GRAFOIL/(4) 1.5 $LBFT^3$ FIBERGLASS/.040 DECO DECORATIVE FILM INNER SKIN)



TEMPERATURES DURING TEST OF NARROW BODY FUSELAGE CROSS SECTION
(WITH (1) 1.5" THICK K-25 LITOFLEX FOAM/.040 DECORATIVE FILM & ALUMINUM INNER SKIN)



SCHEDULE RESPONSIBILITY

STATUS RESPONSIBILITY

RTOP NO.: 510

RTOP TITLE: FIRE RESISTANT MATERIALS ENG.

LAST SCHEDULE CHANGE

STATUS AS OF

	MILESTONES
1	AIR RESEARCH CONTRACT
2	POOL FIRE TESTS (PHASE I)
3	FABRICATION OF TEST PANELS
4	ASSEMBLE, INSTRUMENT, AND TEST
5	OF 10' X 10' PANELS (PHASE II)
6	REFURBISH 737 (AIR RESEARCH)
7	-PROCUREMENT OF GFE
8	-PROCUREMENT OF CFE
9	-FABRICATION AND INSTALL
10	FULL SCALE TEST (1)
11	-INSTRUMENT & CHECKOUT
12	-CONDUCT TEST (PHASE III)
13	SECOND FULL SCALE TEST (DOOR
14	OPEN) (PHASE III)
15	
16	
17	
18	
19	
20	

NOTES:

FIRE BARRIER DECISION DATE

FINAL DECISION DATE

MSC Form 300A (Feb 71) NASA — MSC

RESEARCH AND TECHNOLOGY OBJECTIVE AND PLAN (CONTINUATION SHEET)

ORIGINAL PAGE IS OF POOR QUALITY

SUMMARY

- SEAT CUSHIONS
  - FINAL CONFIGURATION CONTINGENT ON TEST RESULTS FROM SwRI AND DAC
  - POLYIMIDE FOAM A PROMISING CANDIDATE
- UPHOLSTERY AND ASSOCIATED SEAT MATERIALS
  - TEXTILE DEVELOPMENT FOR UPHOLSTERY AND ASSOCIATED SEAT MATERIALS PROHIBITIVE IN COST AND TIME
  - THE BEST STATE-OF-THE-ART MATERIALS AVAILABLE AT THE SCHEDULED TIME WILL BE PROCURED
- WALL AND CEILING PANELS
  - LOCKHEED DEVELOPED PANELS OFFER WEIGHT SAVINGS OVER ALUMINUM
  - FORTY LOCKHEED PHENOLIC/GLASS PANELS BEING SUPPLIED UNDER PRESENT CONTRACT
  - FLUOREL/GLASS PANELS HAVE SUPERIOR ACOUSTICAL AND FIRE BARRIER PROPERTIES
- FLOOR PANELS
  - MOST PROMISING IS RIGID POLYIMIDE FOAM FILLED HONEYCOMB CORE WITH PHENOLIC/GLASS FACE SHEETS
- CARPET AND CARPET UNDERLAY
  - COMMERCIALLY AVAILABLE WOOL AND WOOL BLENDS ARE ADEQUATE
  - CARPETS AND UNDERLAY NOT SIGNIFICANTLY INVOLVED IN AIRCRAFT FIRES DURING EVACUATION
  - POLYIMIDE FOAM UNDERLAY PROVIDES GOOD FIRE BARRIER

SUMMARY (CONTINUED)

- WINDOWS
  - AMES-INDUSTRY DEVELOPMENT ONLY IMPROVEMENT AVAILABLE
- CARGO BAY LINERS
  - POLYIMIDE/GLASS AND PHENOLIC/GLASS DEVELOPMENTS APPEAR PROMISING
  - ADVANCED LINERS NOT ESSENTIAL FOR FULL-SCALE TESTS IF FUSELAGE FIRE BARRIER PROVES ADEQUATE; NEW FLOOR PANEL PROVIDES EXCELLENT BARRIER TO FIRES BENEATH THE CABIN
- INSULATION BAGGING
  - CERAMIC FIBER SHOWS PROMISE TO HOLD THERMAL-ACOUSTICAL INSULATION IN PLACE WHEN TEDLAR BURNS OFF
- THERMAL-ACOUSTICAL INSULATION
  - POLYIMIDE FOAM PROMISING CANDIDATE IF ACOUSTICAL AND FIRE BARRIER PROPERTIES CAN BE UPGRADED
  - CERAMIC FOAM MAY BE CANDIDATE IF DEVELOPMENT CAN KEEP PACE WITH FULL-SCALE TEST SCHEDULE
  - LITAFLEX AND CERAMIC-ASBESTOS MAY BE INCLUDED IF OSHA REQUIREMENTS CAN BE MET
  - GRAPHOIL PROVIDES ADDITIONAL FIRE BARRIER PROTECTION FOR THERMAL-ACOUSTICAL INSULATION BUT IS EXPENSIVE

D. SUPKIS

DEVELOPMENT OF PROCESSES AND TECHNIQUES FOR MOLDING FIRE RESISTANT POLYMERIC MATERIALS

CONTRACT NAS 9-15405
LOCKHEED-CALIFORNIA COMPANY
BURBANK, CALIFORNIA

OBJECTIVES

- SELECT FIRE-RETARDANT MATERIALS FOR MOLDING AIRCRAFT PARTS
- EVALUATE MATERIALS FOR FLAMMABILITY AND THERMAL STABILITY [illegible]IES
- DEVELOP PROCESSES AND TECHNIQUES FOR FORMING THESE MATERIALS BY COMPRESSION, INJECTION AND THERMOFORM MOLDING

COMPRESSION MOLDING DATA

Property	Lac.22-1339 Phenolic Glass	CIBA/GEIGY FIBER DUX 917 Phenolic/Glass	NARMCO 8250 Phenolic Glass	Solar Intl Polyimide Glass	3M Fluorel	Requirement
Density, GM/CC	1.90	1.90	1.90	1.50	≈ 1.75	1.30 (Max)
Heat Deflection, °C @ 264/PSI	200	175	175	204	≈ 180	121 (Min)
Flammability Test FAR 25.853 60 Sec. Vertical						
Flame Time, sec.	3	0	3	0	0	15 (Max)
Burn length, in.	1.32	2.44	1.52	1.20	1.08	6 (Max)
Burntime-Drippings, sec.	0	0	0	0	0	3 (Max)
Smoke Obscuration Ds(6Min)Flaming	8.0	8.8	8	3	10	75 (Max)
Limiting Oxygen Index	40	30	40	60	60	35 (Min)
Thermogravimetric Analysis, °C	390	390	390	590	476	205 (Min)
Material Cost, $/LB	2.25	6.75	5.60	11.25	8.00	20% increase over present in prod. quantities (Max)
Handling Properties	Adequate	Adequate	Adequate	Currently limited to simple parts	Adequate	Same as present materials
Availability	Production Quantities	Production Quantities	Production Quantities	Limited Production	Limited Production	Production Quantities

DISCUSSION OF RESULTS

COMPRESSION MOLDING

- PHENOLIC MOLDINGS MEET FLAMMABILITY, SMOKE, AND THERMAL REQUIREMENTS
- TEDLAR DECORATIVE FILM INCREASES SMOKE AND BURN LENGTH
- SOLAR POLYIMIDE MOLDABLE BUT REQUIRES PROCESSING INSTRUCTION TO CONVERTERS
- SELECTION OF FLUOREL/GLASS FABRIC OR FLUOREL/GLASS MAT CONTINGENT ON EVALUATION OF PRODUCTION RUNS

INJECTION MOLDING DATA

Property	Polycarbonate Lexan 940	Arom. Polyest. E200-3Z	Polyphenylsulfone Radel 5010N	Polyether-sulfone PES KM-1	Requirements
Density, Gm/CC	1.21	1.19	1.29	1.37	1.30 (Max)
Heat Deflection °C @ 264 psi	132	170	204	190	121 (Min)
Flammability Test FAR 25.853 60 Sec. Vertical Flametime, Sec	5	2	1	1	15 (Max)
Burn length, Inches	3.00	2.48	2.8	3.40	6 (Max)
Burntime-Drippings, Sec	2	7	0	0	3 (Max)
Smoke Obscuration D_s (6 Min) Flaming	110	90	3.2	20	75 (Max)
Limiting Oxygen Ind.	35	33	38	36	35 (Min)
Thermogravimetric Analysis °C	440	329	570	299	205 (Min)
Material Cost, $/LB	2.50	8.00	15.00	8.00	20% Increase over present in prod. Quan
Availability	Prod.Quant.	Dev. Quant.	Limited Pilot blank quant.	Limited Prod.	Prod.Quant.
IZOD Impact, Notched FT-LBS/INCH	10	3	12	1.6	3.0 (Min)
Tensile Strength PSI, Min.	8500	12,000	10,400	12,000	6000 (Min)
Elongation, %	90	60	60	10	20 (Min)

DISCUSSION OF RESULTS

INJECTION MOLDING

- POLYETHERSULFONE (PES) AND POLYPHENYLSULFONE (PPS) HAVE BETTER FLAMMABILITY PROPERTIES THAN LEXAN 940
- PES AND PPS MATERIALS AND PROCESSING COSTS MUCH HIGHER THAN LEXAN 940
- MONSANTO'S POLYESTER FAILS FLAMMABILITY TESTS
- LEXAN 940 MELTS AND DRIPS BURNING PARTICLES

THERMOFORM DATA

Property	Polycarbonate Lexan F-6000	Polycarbonate Lexan EF-6000	Polyethersulfone PES KM-1	Requirements
Density, Gm/CC	1.21	1.21	1.37	1.40 (Max)
Heat Deflection °C @ 264 psi	132	122	190	121 (Min)
Flammability Test FAR 25.853				
Flame time, seconds	4	97	0	15 (Max)
Burn length, inches	3.0	7.4	3.4	6 (Max)
Burntime-drippings, sec.	1.0	1.0	0	3 (Max)
Smoke Obscuration D_s (6 Min) Flaming	110	120	20	75 (Max)
Limiting Oxygen Index	33.5	33	36	35 (Min)
Thermogravimetric Analysis °C	440	440	550	205 (Min)
Material Cost $LB	3.00	3.00	8.00	20%, Max, over present materials
Availability	Production Quantities	Limited Production	Limited Production	Production Quantities
IZOD Impact, Notched FT-LBS/INCH	10	12	1.3	3.0 (Min)
Tensile Strength psi minimum	9,800	9,600	12,000	6,000 (Min)
Elongation %	75	75	3	20 (Min)
180° Peel/LB/INCH	10	10	7	8 (Min)
Cleaner and Solvent Resist.	Fair	Fair	Good	Good

SUMMARY OF RESULTS

THERMOFORM

- POLYCARBONATE EF 6000 CLEANABILITY AND FLAMMABILITY PROPERTIES DO NOT MEET REQUIREMENTS

- POLYCARBONATE F6000 BETTER BUT MELTS AND DRIPS BURNING PARTICLES

- POLYETHERSULFONE SATISFACTORY BUT SPECIAL EXPENSIVE DIES ARE REQUIRED FOR THERMOFORMING

CONCLUSIONS

COMPRESSION MOLDING

- PHENOLICS MEET ALL REQUIREMENTS
- PHENOLIC FORMULATIONS COMMERCIALLY AVAILABLE FOR FY 80 TESTS
- SELECTION OF ONE OF TWO FLUOREL/GLASS CONFIGURATIONS TO BE MADE AFTER EVALUATION OF PRODUCTION RUNS
- FLUOREL/GLASS MATERIALS OFFER ADVANTAGES IN WEIGHT SAVINGS, ACOUSTICS, AND FIRE BARRIER PROPERTIES

INJECTION MOLDING

- PES KM-1, POLYETHERSULFONE MAY SHOW PROMISE FOR REPLACING POLYCARBONATE IF DEVELOPMENT CONTINUES

THERMOFORMING

- NO THERMOFORMABLE MATERIALS HAS BEEN IDENTIFIED THAT MEETS JSC REQUIREMENTS

D5

N79-31171

DEVELOPMENT OF FIRE-RESISTANT, LOW SMOKE GENERATING, THERMALLY STABLE END ITEMS FOR COMMERCIAL AIRCRAFT AND SPACECRAFT USING A BASIC POLYIMIDE RESIN

by

J. Gagliani, Solar Turbines International

This presentation is divided into four parts. The first part covers experimental data pertinent to flexible resilient foams followed in order by low density wall panels, high strength floor panels and thermal acoustical insulation.

The schedule which covers each task under study is shown in Figure 1 and the interrelations between the various products and tasks are shown in Figure 2. The tasks and the objectives of the phase of the program dealing with f   ble resilient foams are shown in Figure 3.

These objectives were achieved by modification of the resin compositions through advanced synthesis and by optimization of all the process parameters. Modification of the basic prepolymers was carried out by alteration of the resins with aromatic and aliphatic diamines. The corresponding terpolyimide foams obtained were then evaluated for the most critical parameters as shown in Figure 4 and Figure 5. As reported, aromatic terpolyimide foams did not produce the desired compression set properties (15% loss maximum after 24 hours at 90% compression) and were eliminated from further study.

The properties of foam derived from terpolyimides modified with aliphatic diamines approached the requirements for compression set (see Group IV) and met the fatigue requirements.

Next, an evaluation of the effect of the heterocyclic diamine component on the compression set of the foams was carried out. The data of Figure 6 show that higher ratio of the heterocyclic diamine produces foams with improved compression set properties, however when ratios higher than 0.4 were used the foams obtained were highly reticulated and not suitable for sealing applications.

The two candidates selected, specifically the 1701-1 and 1702-1 were further evaluated to study the contribution of surfactants on compression set properties. These data are shown in Figure 7 where the improved properties of the 1701-1 foams are clearly shown. At this point of the program, four polyimides precursors were selected for further evaluation in further studies.

The efforts were continued with evaluation of the foaming process parameters. The foaming process consists of simply placing the powder precursor on a suitable substrate followed by foaming in a microwave oven. The expanded mass is then heat cured at 500°-550°F to obtain resiliency and flexibility.

The foaming parameters studied were:

- Power output
- Powder loading
- Preheat temperature
- Preheat time
- Foaming time
- Curing temperature

Figure 8 shows that power output in the range of 2.5 to 10 kW produces foaming but higher power outputs are desirable since they cause incipient curing. The effect of powder loading on the foaming behavior of polyimide precursors is shown in Figure 9. Powder loadings higher than 2.4 Kg/m^2 are essential. The powder precursor does not have to be preheated as shown in Figure 10, however when the preheating time is extended and the temperature is maintained at 250°F improved compression set properties are obtained (Figure 11).

The foaming time in the high frequency field has also been found to be critical as shown in Figure 12 where improved compression properties are achieved by using higher power outputs and longer foaming time. The last step in the preparation of the polyimide foam involves curing the expanded mass to achieve flexibility and resiliency.

The data of Figure 13 show that higher temperature and longer curing time cause foam degradation and poor compression set properties. The data points represent an average of six determinations carried out on large size foams (1000 g of powder precursors). This concludes the work carried out in the task dealing with flexible resilient foams.

The next study involved evaluation of processes and compositions to fabricate wall panels. The tasks and objectives are shown in Figure 14. Optimization of the polyimide compositions previously developed was achieved with the development of rigid foams meeting the density requirements. This study was continued with development of new techniques to produce low density panels in a one-step microwave process as shown in Figure 15. The precursor and additives are mixed, spread over a substrate and foamed in a microwave cavity by restricting the rise. The finished rigid panel is characterized by possessing low density core and high density skins.

The same technology is now being used to produce high strength floor panels. The tasks and objectives of this task are shown in Figure 16.

A major task of this program was the development of thermal acoustical polyimide materials to replace conventional glass batting insulation. The tasks and objectives of this last study are shown in Figure 17. The studies dealing with advanced synthesis and with foaming studies carried out in the task dealing with flexible resilient foams are completely applicable to fabrication of polyimide foams for use in thermal acoustical insulation. The optimization of glass batting and foams was then initiated. Figure 18 shows the effect of polyimide foam coatings on the burnthrough resistance of PF-105-700 fiberglass batting. The coatings were applied by spray techniques using liquid polyimide precursors and foamed at 550°F. As shown, polyimide coatings improve the burnthrough resistance of the fiberglass batting at any resin loading. The burnthrough requirements were met at a loading of 0.048 Kg/m^2. The tests were made with a Meker burner and carried out until burnthrough occurred.

A second approach to the problem involved modification of the polyimide foams with additives to produce improved fire resistance. Figure 19 shows the effect

of a combination of glass microballoons and glass strands on the burnthrough resistance of polyimide foams. The filled foam did not fail after 10 minutes exposure to the Meker burner, while the unfilled foam failed in 2.5 minutes. The two candidate materials, the polyimide coated fiberglass batting and the filled polyimide foams were then tested in the NASA-JSC Fire Rig, but did not meet the minimum burnthrough requirements (5 minutes). Failure appeared to be more mechanical due to thermal cracking, than to material failure.

To reduce the thermal stresses and improve the burnthrough resistance, new crosslinked polyimide foams have been developed which are [illegible] under evaluation.

The program is continuing with the major tasks listed in Figure 20.

NAS9-15484
February 1, 1979

Development of Fire-Resistant, Low Smoke Generating, Thermally Stable End Items for Commercial Aircraft and Spacecraft Using a Basic Polyimide Resin

Submitted to:

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Attn: Norman R. Lamb
Mail Code: BC721 (3)

SOLAR TURBINES INTERNATIONAL
An Operating Group of International Harvester
2200 Pacific Highway, P.O. Box 80966, San Diego, California 92138

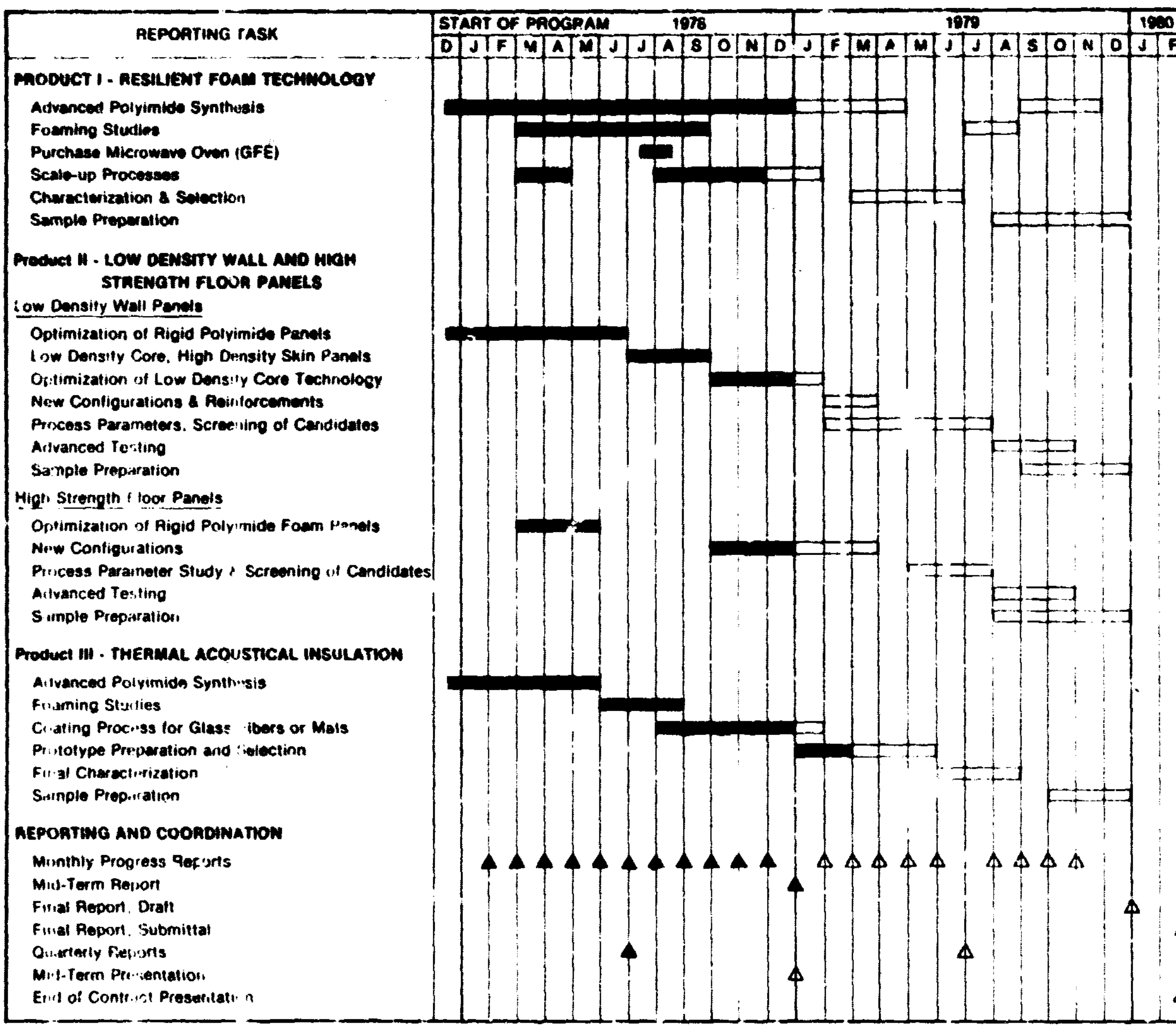


Figure 1. Program Schedule

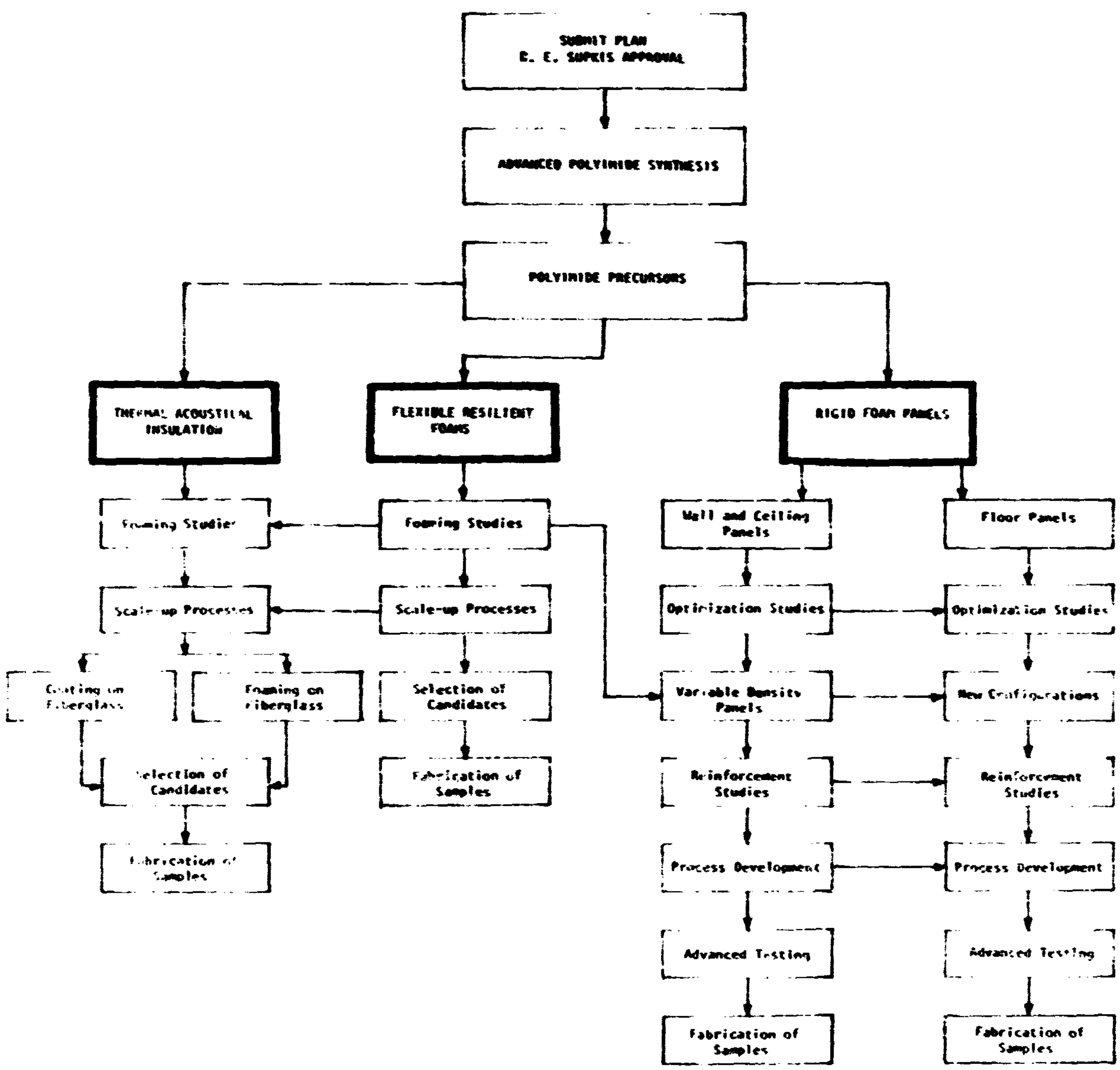


Figure 2. Program Flow Diagram

FLEXIBLE RESILIENT FOAMS

TASKS

- ADVANCED POLYIMIDE SYNTHESIS
- FOAMING STUDIES
- SCALE-UP PROCESSES

OBJECTIVES

- IMPROVEMENT OF COMPRESSION SET AND FATIGUE PROPERTIES

  OPTIMIZATION OF ALL PROCESSES FROM RESIN SYNTHESIS TO FINAL FOAMING

  SCALE-UP TO LARGE SIZE FOAMS

Figure 3. Flexible Resilient Foams

Foam Resin Number	Composition	Mole Ratio	Density kg/m³	Density lbm/ft³	Resiliency Ball Rebound	% Loss After 30 Minutes Recovery	Type of Foam
1710-1-4	BTDA:2,6DAP:MDA:DADPS	1:0.3:0.65:0.05	—	—	—	—	Flexible, resilient, DADPS not compatible
1710-1-5	BTDA:2,6DAP:MDA:DADPS	1:0.3:0.55:0.15	—	—	—	—	DADPS not compatible
1710-1-6	BTDA:2,6DAP:MDA:DADPS	1:0.3:0.40:0.30	—	—	—	—	DADPS not compatible
1710-1-7	BTDA:2,6DAP:MDA:DADPE	1:0.3:0.65:0.05	10.9	0.68	50-60	58.0	Flexible, resilient, good homogeneous cellular structure
1710-1-8	BTDA:2,6DAP:MDA:DADPE	1:0.3:0.55:0.15	19.9	1.24	60-70	50.0	Flexible, resilient, good homogeneous cellular structure, some striations
1710-1-9	BTDA:2,6DAP:MDA:DADPE	1:0.3:0.4:0.30	16.8	1.05	70	48.4	Flexible, resilient, good structure; some striations
1710-1-10	BTDA:2,6DAP:MDA:TDA	1:0.3:0.65:0.05	8.2	0.51	60-70	52.5	Flexible, resilient; homogeneous cell structure
1710-1-11	BTDA:2,6DAP:MDA:TDA	1:0.3:0.55:0.15	8.7	0.54	90	49.1	Flexible, resilient; homogeneous cell structure; some striation present
1710-1-12	BTDA:2,6DAP:MDA:TDA	1:0.3:0.4:0.30	12.2	0.76	60	51.7	Flexible, resilient; flaws and striations
1710-1-13	BTDA:2,6DAP:MDA:DAT	1:0.3:0.65:0.05	8.17	0.51	80-85	4.44	Flexible, resilient, homogeneous cellular structure
1710-1-14	BTDA:2,6DAP:MDA:DAT	1:0.3:0.55:0.15	9.77	0.61	>90	39.4	Flexible, resilient, homogeneous cellular structure
1710-1-15	BTDA:2,6DAP:MDA:DAT	1:0.3:0.4:0.3	9.93	0.62	80	40.8	Flexible, resilient, medium size cellular structure with some flaws
1710-1-16	BTDA:2,6DAP:MDA:XDA	1:0.3:0.65:0.05	9.93	0.62	75-80	59.0	Flexible, resilient, fine cellular structure
1710-1-17	BTDA:2,6DAP:MDA:XDA	1:0.3:0.55:0.15	18.42	1.15	60	52.4	Flexible, resilient fine cellular structure, flaws and striations
1710-1-18	BTDA:2,6DAP:MDA:XDA	1:0.3:0.4:0.3	18.74	1.17	55-60	44.3	Semi-rigid and hard foam with flaws
1710-1-19	BTDA:2,6DAP: Jeffamine AP-22	1:0.3:0.7	6.41	0.4	60	45.3	Flexible, resilient, homogeneous cellular structure

Figure 4. Properties of Advanced Aromatic Terpolyimide Systems

[illegible] Number	Aliphatic Diamine	Density		90% Compression Set % Loss After 30 Minute Recovery	[illegible] Ball Rebound	Foam Characteristics
		lbs/ft^3	kg/m^3			
[illegible]	None	[illegible].538	8.[illegible]	52	55	Flexible, resilient, good structure
Group 1						
1720-1-1	Propyl	1.44	23.0	46	50	Flexible, resilient, good structure
1720-1-8	Butyl	1.32	21.1	63	45	Flexible, resilient, good structure
[illegible]	Hexa	[illegible]	[illegible]	48	[illegible]	Flexible, resilient, good structure
1720-1-3	Octa	0.943	15.1	39	50	Flexible, resilient, good structure
1720-1-4	Dodeca	1.62	25.9	42	50	Flexible, resilient, striated
1720-1-5	Jeffamine D-230	1.11	17.8	21	70	Flexible, resilient, large cell size, brittle
1720-1-6	Jeffamine D-400	--	--	--	--	Poor foam, collapsed on heating
1720-1-7	Jeffamine D-2000	--	--	--	--	Poor foam, collapsed and degraded on heating
Group 2						
1720-1-12	Propyl	0.840	13.4	40	40	Flexible, resilient, good structure
1720-1-9	Butyl	1.25	20.0	53	53	Flexible, resilient, good structure
1720-1-13	Hexa	0.817	13.1	47	55	Flexible, resilient, good structure
1720-1-10	Octa	1.40	22.4	43	35	Flexible, resilient. good structure
1720-1-14	Dodeca	3.32	53.0	46	70	Flexible, resilient, poor structure
1720-1-11	Jeffamine D-230	--	--	--	--	Brittle, very large cell size, poor foam
Group 3						
1720-1-15	Propyl	--	--	--	--	Rigid foam, collapsed and degraded on heating
1720-1-16	Butyl	1.48	23.7	63	50	Flexible, resilient, fair structure
1720-1-17	Hexa	1.37	21.9	71	50	Flexible, resilient, fair structure
1720-1-18	Octa	1.33	21.2	68	45	Flexible, resilient, good structure
1720-1-19	Dodeca	0.778	13.5	45	70	[illegible], resilient, good structure
Group 4						
1720-1-25	Propyl	1.33	21.2	40	50	Flexible, resilient, good structure
1720-1-2[illegible]	Butyl	0.835	13.	25	45	Flexible, resilient, good structure
1720-1-24	Hexa	1.44	23.0	30	55	Flexible, resilient, medium cell size
1720-1-21	Octa	0.845	13.5	22	70	Flexible, resilient, medium cell size
1720-1-23	Dodeca	0.565	[illegible].04	23	65	Flexible, resilient, good structure
1720-1-2[illegible]	Jeffamine D-230	--	--	--	--	Brittle, very large cell size, collapsed on heating
Group 5						
1720-1-26	Butyl	1.15	18.3	31	50	Flexible, resilient, good structure
1720-1-27	Hexa	0.399	6.36	7	55	Flexible, resilient, highly reticulated

Figure 5. Aliphatic Terpolyimide Foam Precursors and Foam Characteristics (1702-1 Resin System)

Foam Resin Number	Composition	Molar Ratio	Concentration of Surfactant AS-2 (%)	% Loss After 30 Minutes Recovery	Type of Foam
1702-1-62	BTDA:2,6DAP:MDA	1:0.3:0.7	0.0125	40.0	Fine, homogeneous cellular structure
1701-1-5	BTDA:2,6DAP:MDA	1:0.4:0.6	0.0125	19.6	Medium-large homogeneous cellular structure
1701-1-7	BTDA:2,6DAP:MDA	1:0.42:0.58	0.0125	12.1	Reticulated foam with medium size cellular structure
1701-1-8	BTDA:2,6DAP:MDA	1:0.44:0.56	0.0125	—	Highly reticulated foam with large and weak ceulluar structure
1701-1-10	BTDA:2,6DAP:MDA	1:0.5:0.5	0.0125	—	Highly reticulated foam with chopped strands like cell structure. Poor - hollow foam

Figure 6. Flexible, Resilient, Polyimide Foams: Effect of Molar Concentration Of 2,6DAP On Compression Set Loss Values

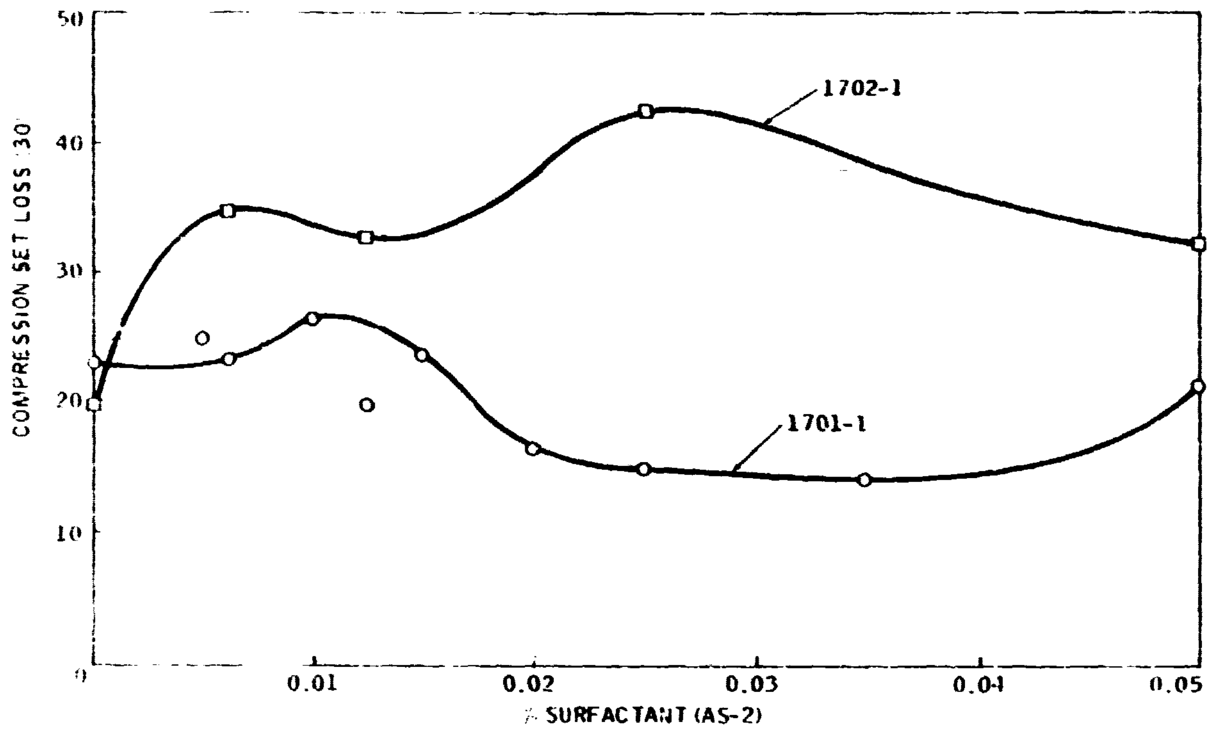


Figure 7. Flexible, Resilient Polyimide Foams; Effect of Surfactant Concentration (AS-2) On Compression Set Loss

Power Output (kW)	Time to Foam (Seconds)	Total Foaming Cycle (Seconds)	Foaming Quality
2.5	120	240	fine cellular structure
5.0	75	210	fine cellular structure
10	60	180	fine cellular structure large portion of foam cured in microwave

Figure 8. Foaming Behavior of 1702-1 Precursors At Various Power Outputs

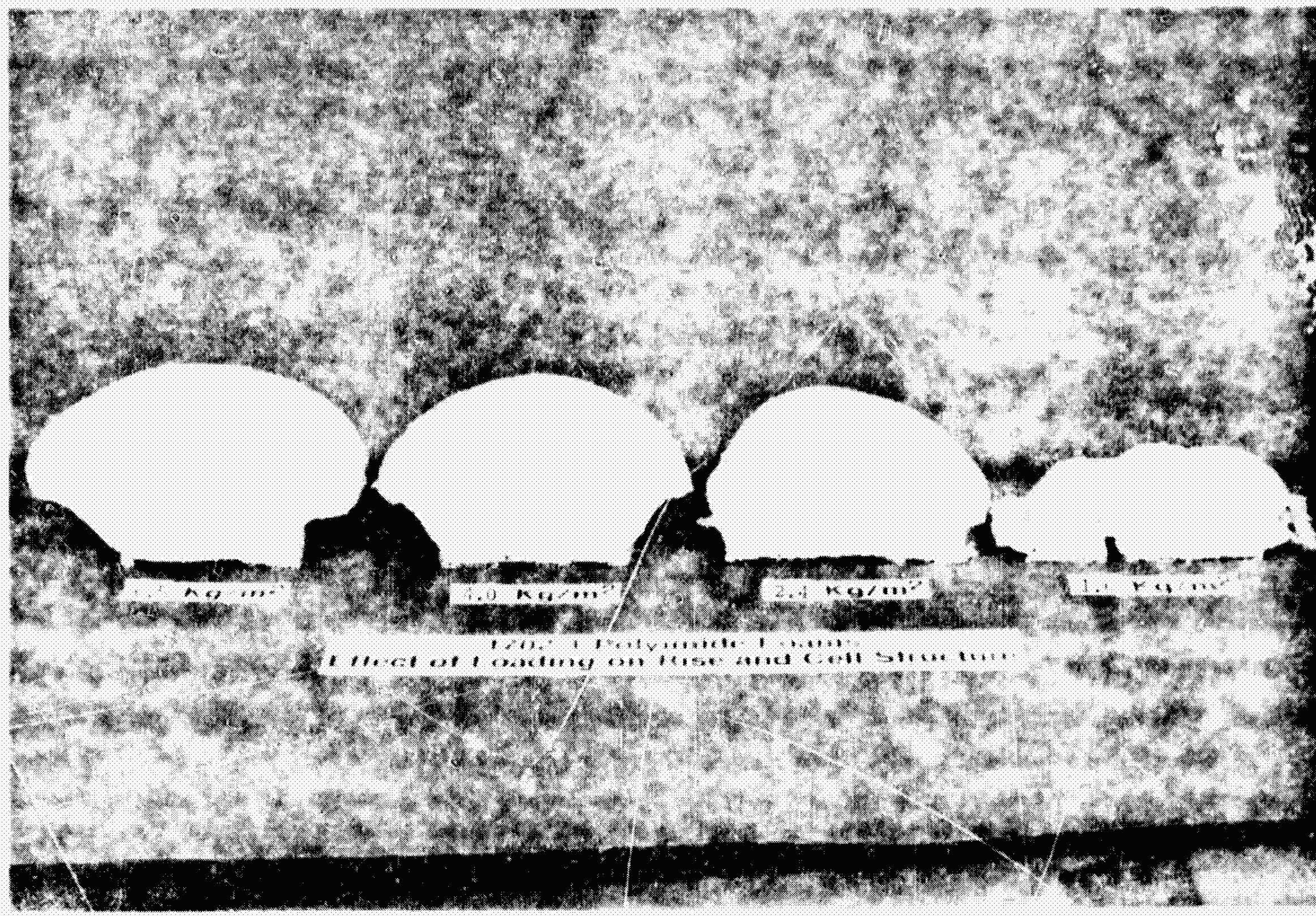


Figure 9. Effects of Powder Loading in Properties of Polyimide Foams

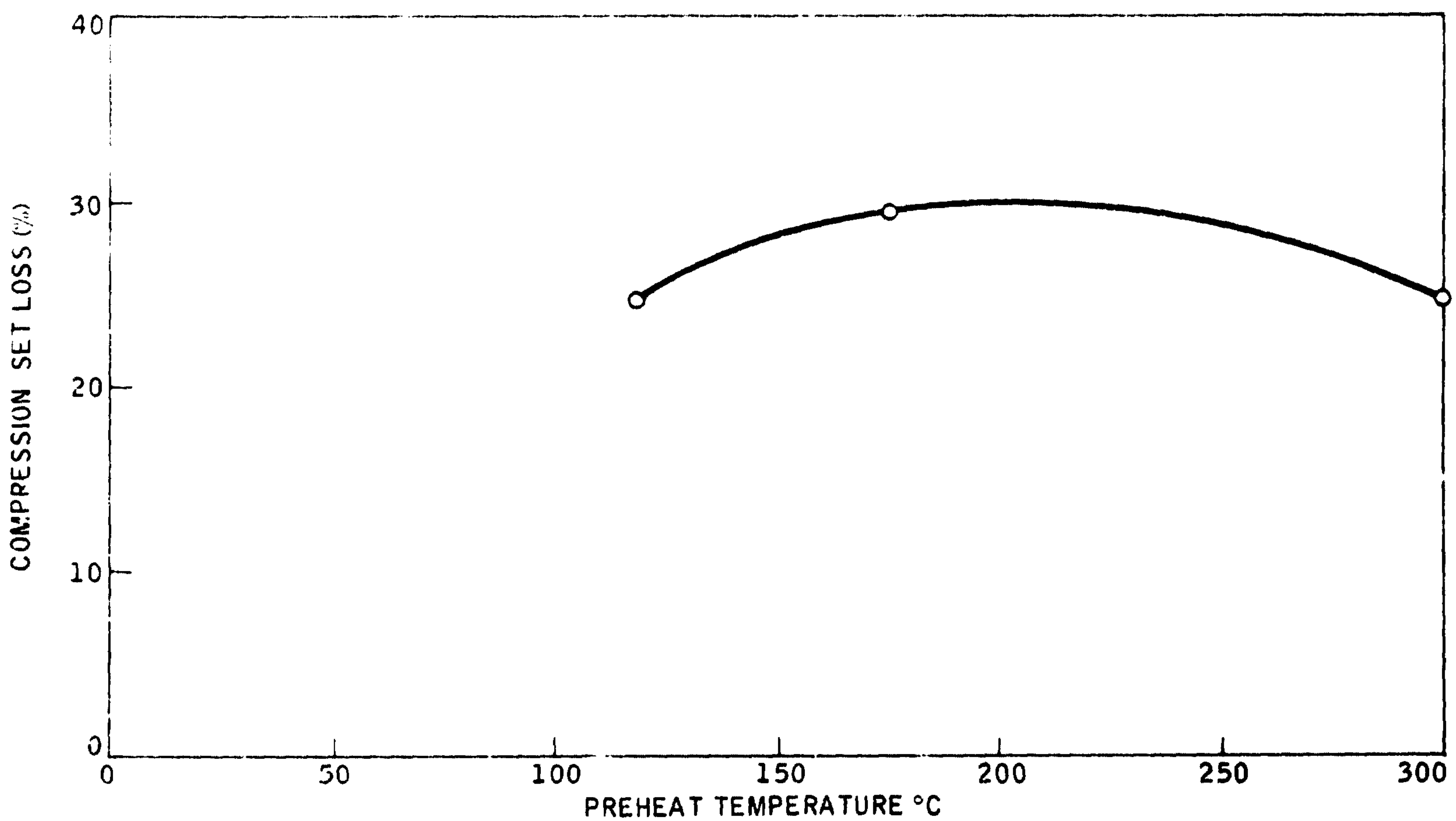


Figure 10. Effect of Preheat Temperature (2 Min.) on Compression Set Loss of 1701-1 Polyimide Foams Modified With 0.015 Percent AS-2

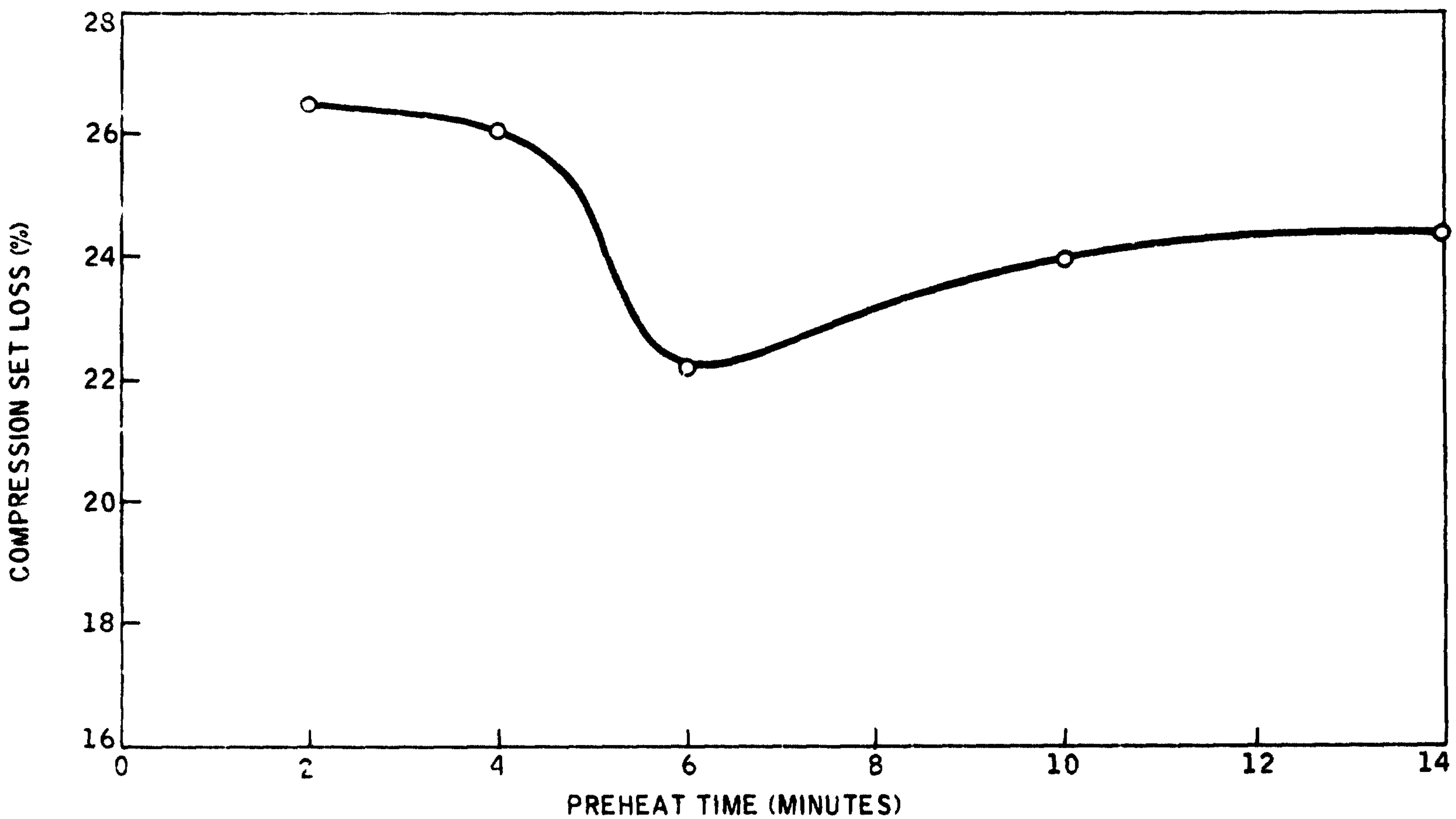


Figure 11. Effect of Preheat Time on Compression Set Loss (250°F) of 1701-1 Polyimide Foams

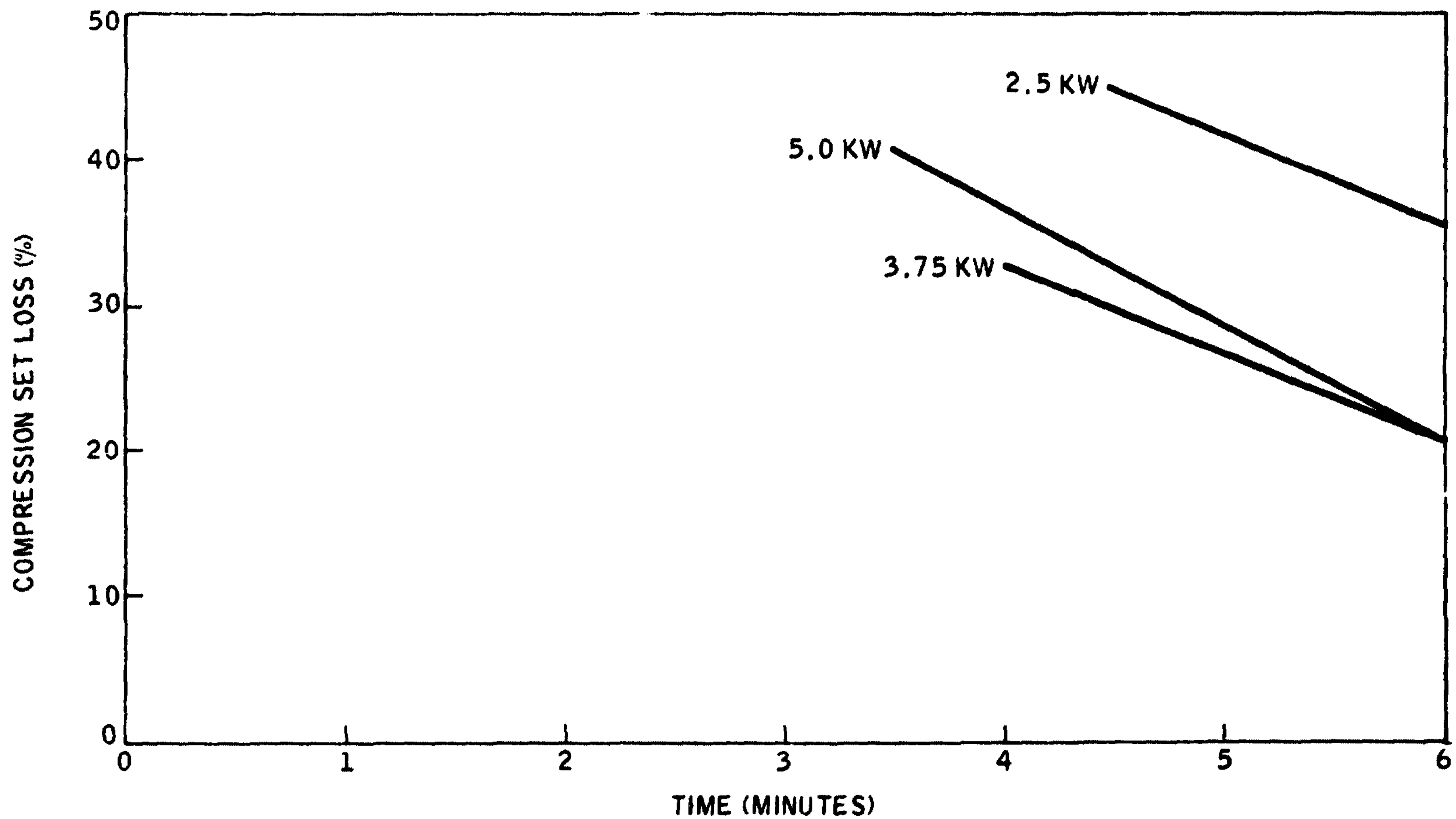


Figure 12. Effect of Foaming Time on Compression Set Loss of Aliphatic Terpolyimide System (1720-1)

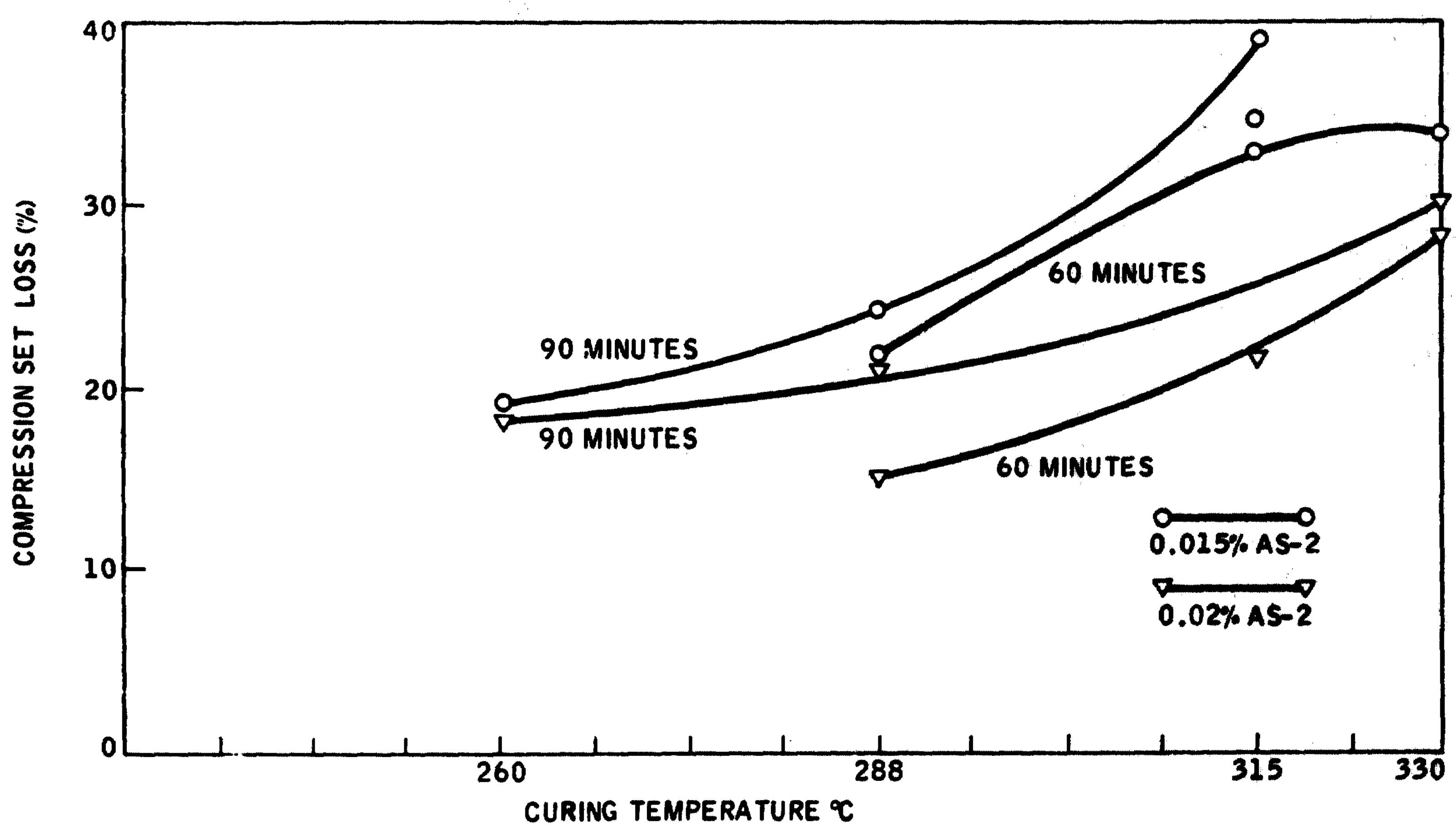


Figure 13. Effect of Curing Temperature on 90% Compression Set Values of Foams Derived from 1701-1 Precursors Modified With 0.015% and 0.02% AS-2 Respectively

LOW DENSITY WALL PANELS

TASKS

- OPTIMIZATION OF RIGID POLYIMIDE FOAM PANELS
- LOW DENSITY CORE, HIGH DENSITY SKIN PANELS
- OPTIMIZATION OF LOW DENSITY CORE TECHNOLOGY

OBJECTIVES

- DEVELOPMENT OF TECHNIQUES TO PRODUCE FINAL WALL PANEL CONFIGURATIONS IN A ONE-STEP PROCESS WITHOUT THE USE OF ADHESIVES.
- FABRICATION OF WALL PANELS HAVING LOW DENSITY CENTERS AND HIGH DENSITY EDGES TO MEET DIRECT SCREW WITHDRAWAL REQUIREMENTS.

Figure 14. Low Density Wall Panels

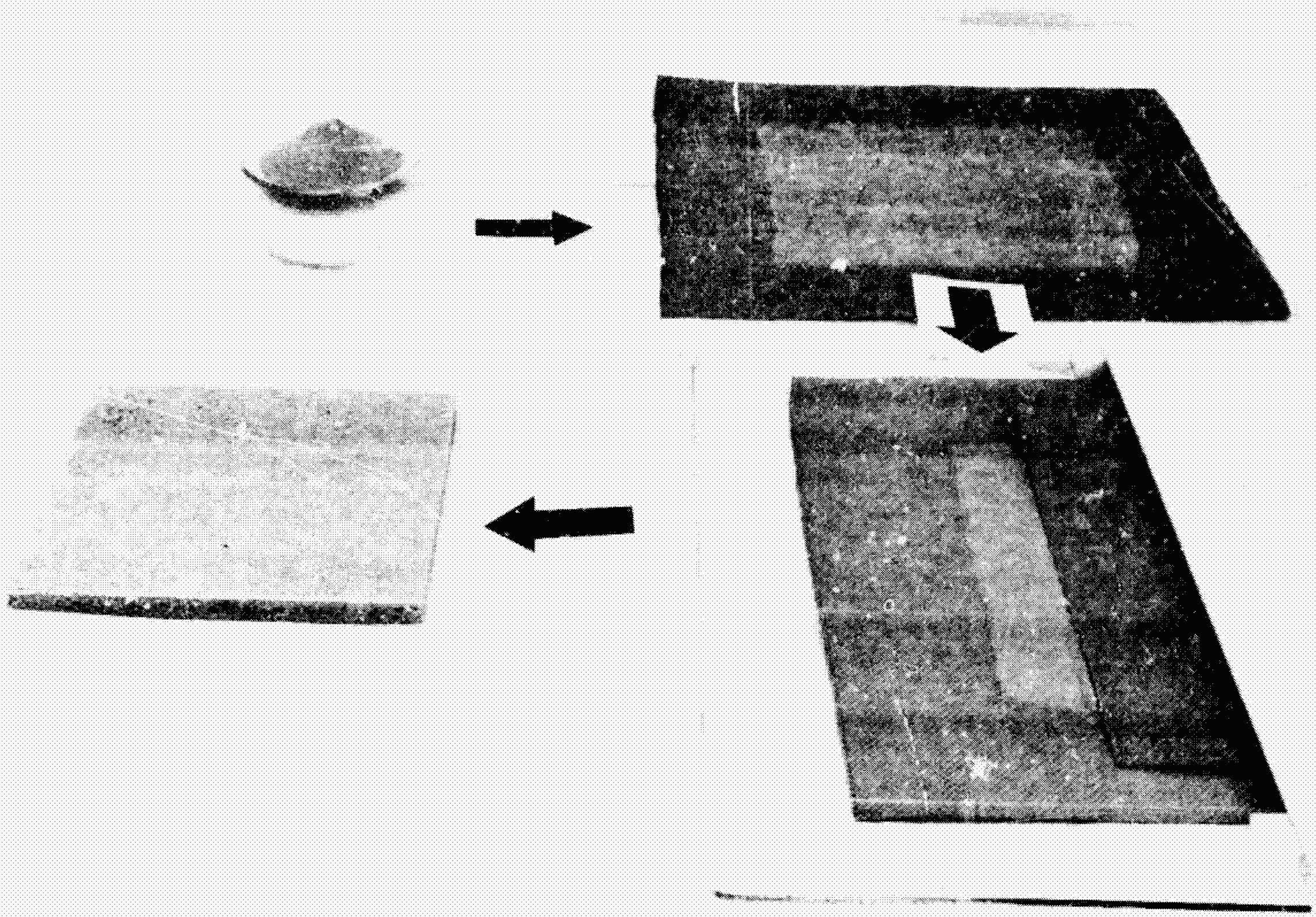


Figure 15. Fabrication of Rigid Low Density Panels From Powder Polyimide Precursors in a One-Step Microwave Process

HIGH STRENGTH FLOOR PANELS

TASKS

- OPTIMIZATION OF RIGID POLYIMIDE FOAM PANELS
- NEW CONFIGURATIONS

OBJECTIVES

- DEVELOPMENT OF PANEL CORE MEETING HIGH TRAFFIC AREA REQUIREMENTS

  DEVELOPMENT OF RIGID PANELS WITH VARIABLE DENSITY CHARACTERISTICS

Figure 16. High Strength Floor Panels

THERMAL ACOUSTICAL INSULATION

TASKS

- ADVANCED POLYIMIDE SYNTHESIS

  FOAMING STUDIES

  COATING PROCESS FOR GLASS FIBERS AND MATS

OBJECTIVES

OPTIMIZATION OF THE BURNTHROUGH PROPERTIES OF THE FOAMS

Figure 17. Thermal Acoustical Insulation

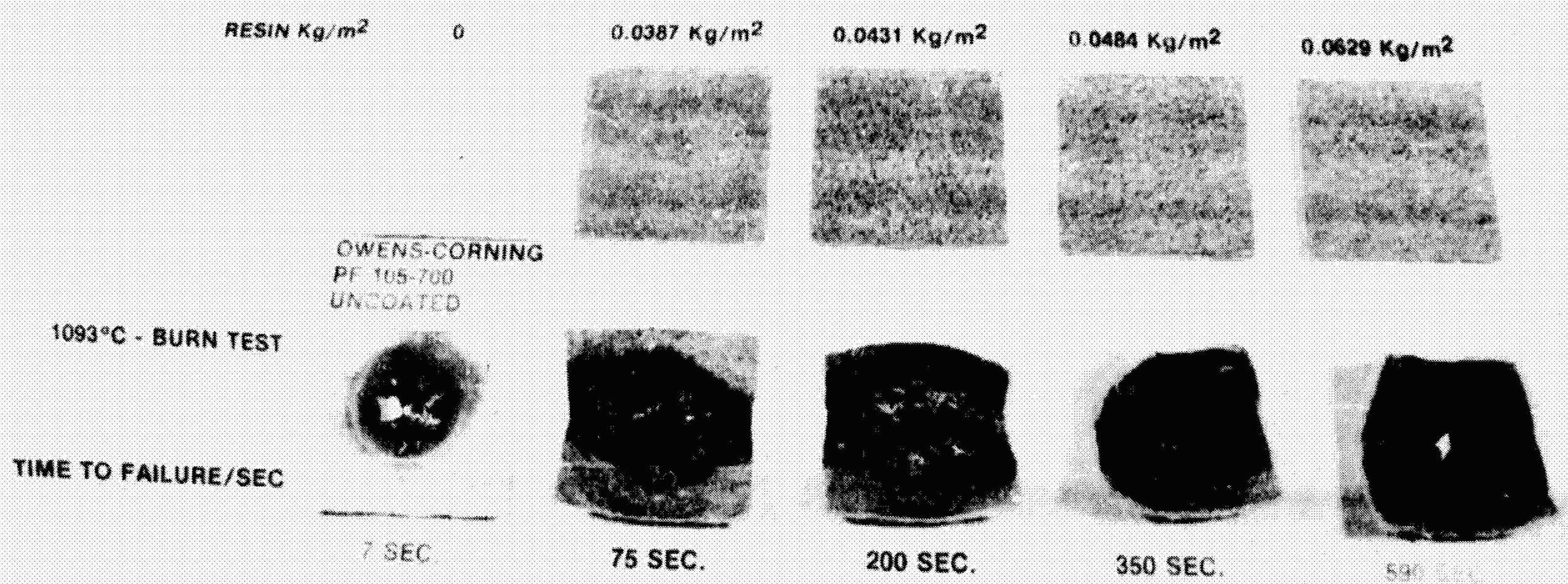
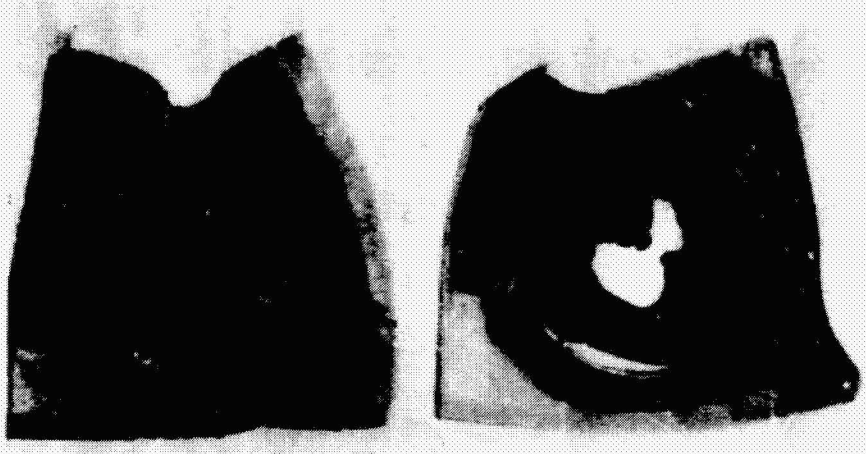


Figure 18. 1702 Polyimide Resin Spray Coated & Foamed on Owens-Corning PF 105-700 Fiberglass 20 x 20 CM Effect of Loading on Burn Test

C-2



GLASS & MICROBALLOONS | UNFILLED

NO FAILURE AFTER TEN MINUTES EXPOSURE | BURNTHROUGH 2.5 MINUTES

Figure 19. Effect of Filers on Burnthrough Characteristics of Polyimide Foam: Left 1702-1, 1.0% AS-2; 20% Glass Strands 3% Microballoons

FUTURE PLANS

- Development of large scale foam processing.
- Fabrication of shaped flexible foams by the use of closed or open molds.
- Optimization of the microwave process to produce rigid panels with densified skins.
- Development of thermal acoustical materials meeting the burnthrough requirements
- Selection of one or more candidates for each of the products under study.

Figure 20. Future Plans

N79-31172 D6

GLOBAL ENCLOSURE FIRE MODELING WITH APPLICATIONS

FIREMEN

FIRE MODELING AND SCALING METHODS

510-56-05

Jay Wm. Stuart

OUTLINE

- Brief review of LeRC limiting energy release criteria
- Application of LeRC to JSC/Boeing ignition source full-scale tests
- Application of LeRC to JSC/DACFIR math-model validation-tests

LIMITING ENERGY RELEASE CRITERIA-LERC

FLAME SPREAD RATE

$\mathring{Q}_S = (\mathring{Q}/A)\, bvt$ (LINEAR)

FUEL SURFACE LIMIT

$\mathring{Q}_f = 2500\, A_f$ (GASOLINE)

VENTILATION LIMIT

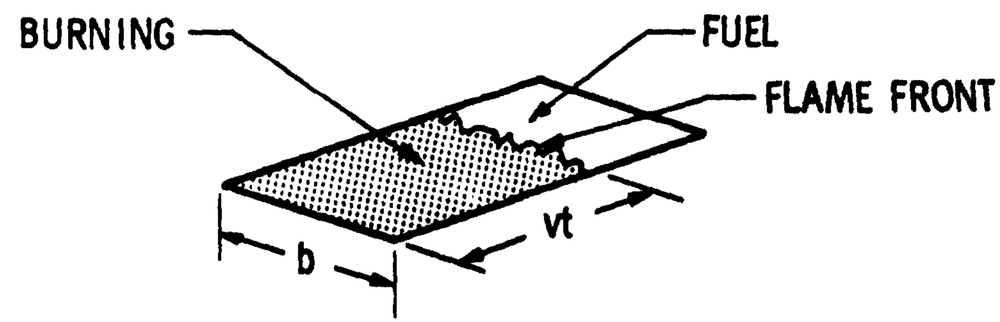
$\mathring{Q}_V = 1580\, AH^{1/2}$

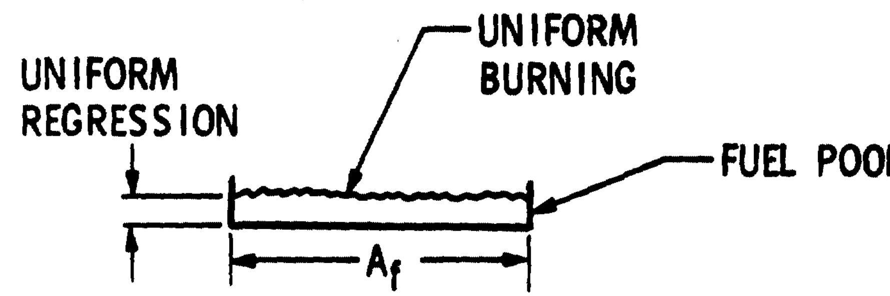
ENCLOSURE VOLUME

$$t_e = \frac{58V_e}{\mathring{Q}}$$

FUEL LOAD

$$t_e = \frac{M_f\, \Delta H}{\mathring{Q}}$$





COMBINED CRITERIA OXYGEN SUPPLY

$$t_e = \frac{Q_e}{2\mathring{Q}}\left(1 - \mathring{Q}_V/\mathring{Q}\right)^{-1}$$

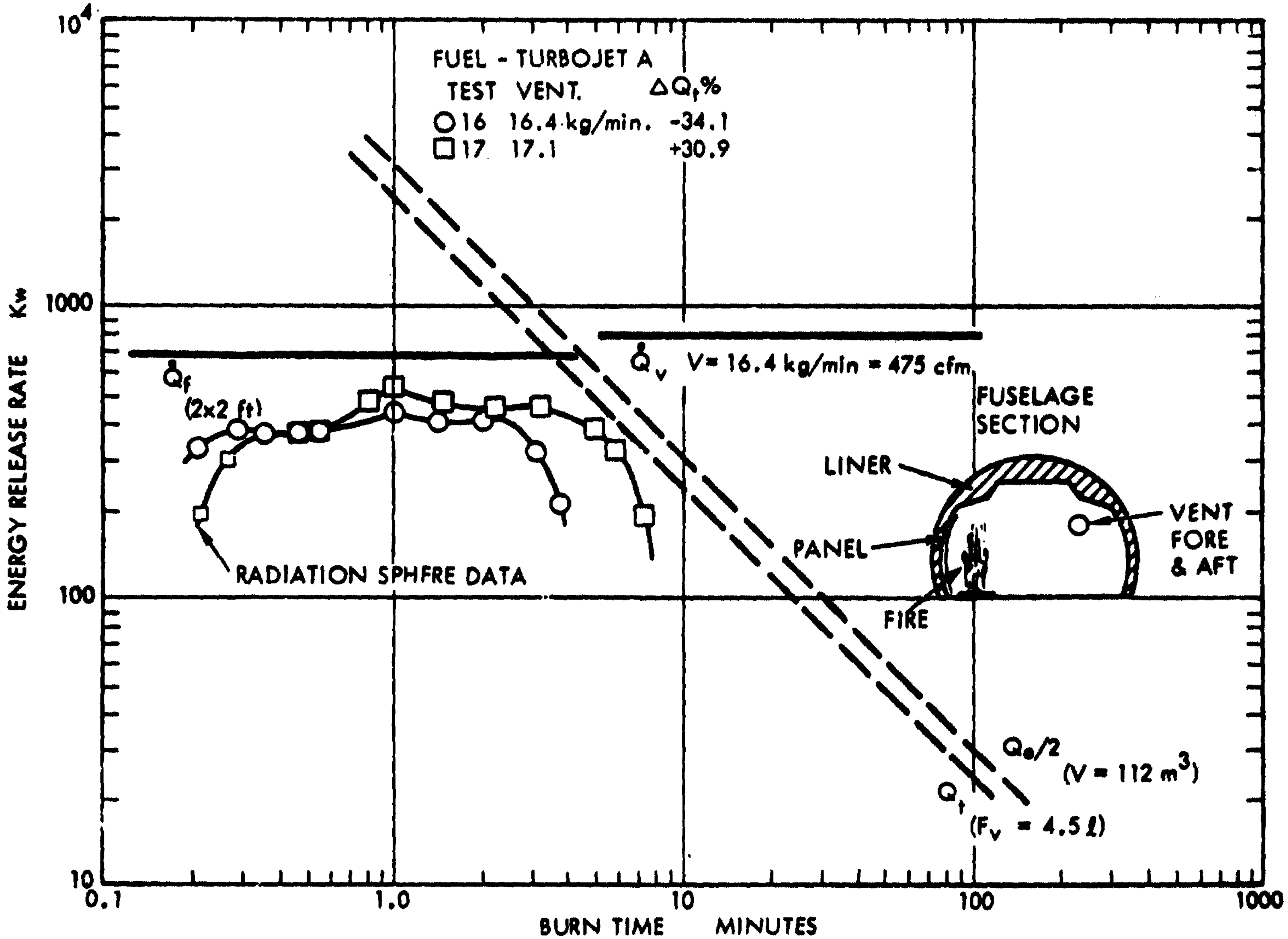
$$Q_e = 58V_e$$

UNITS:

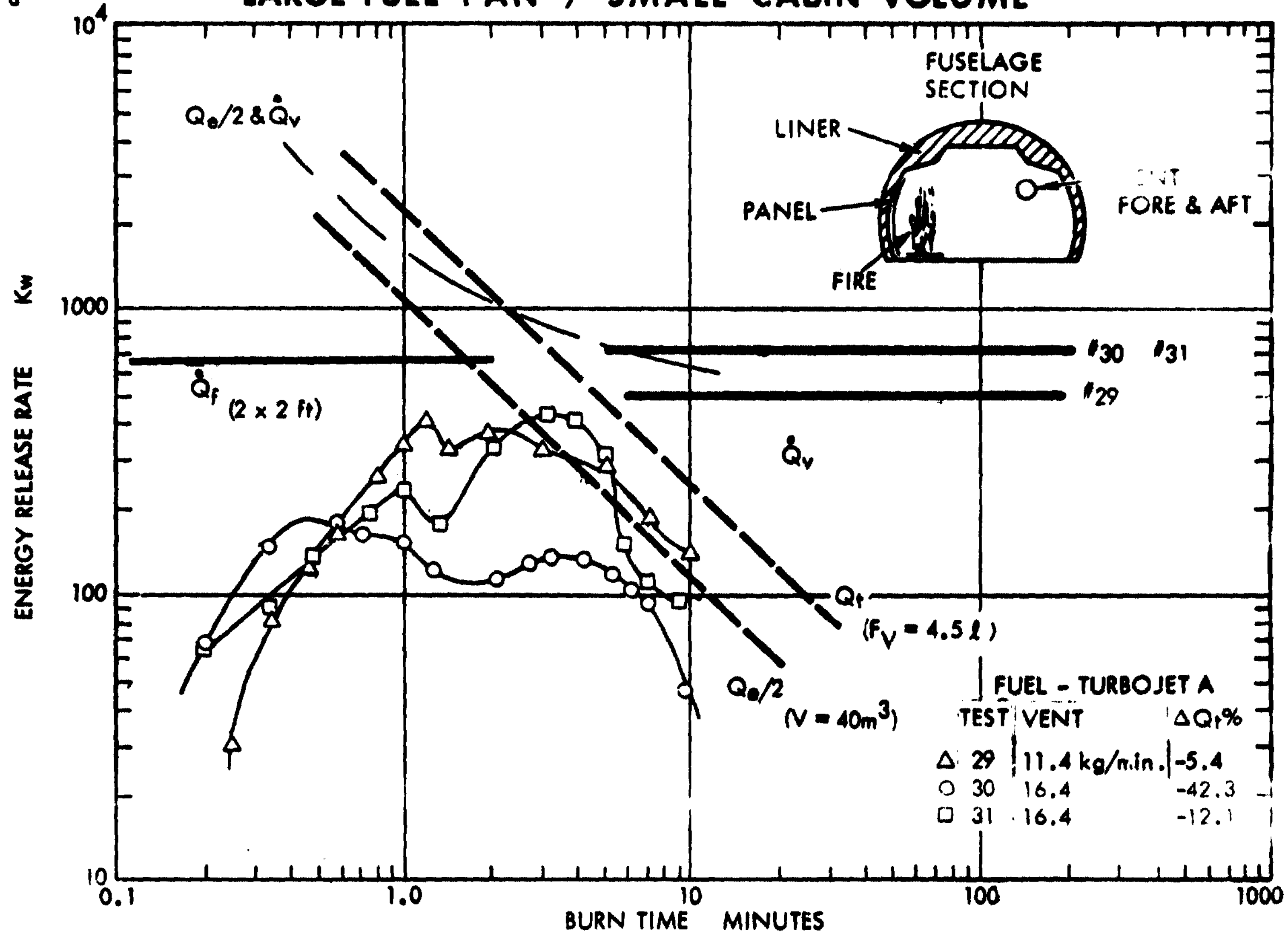
KILOWATTS
METERS
KILOGRAMS
MINUTES

DATA VARIABILITY

LARGE FUEL PAN / LARGE CABIN VOLUME

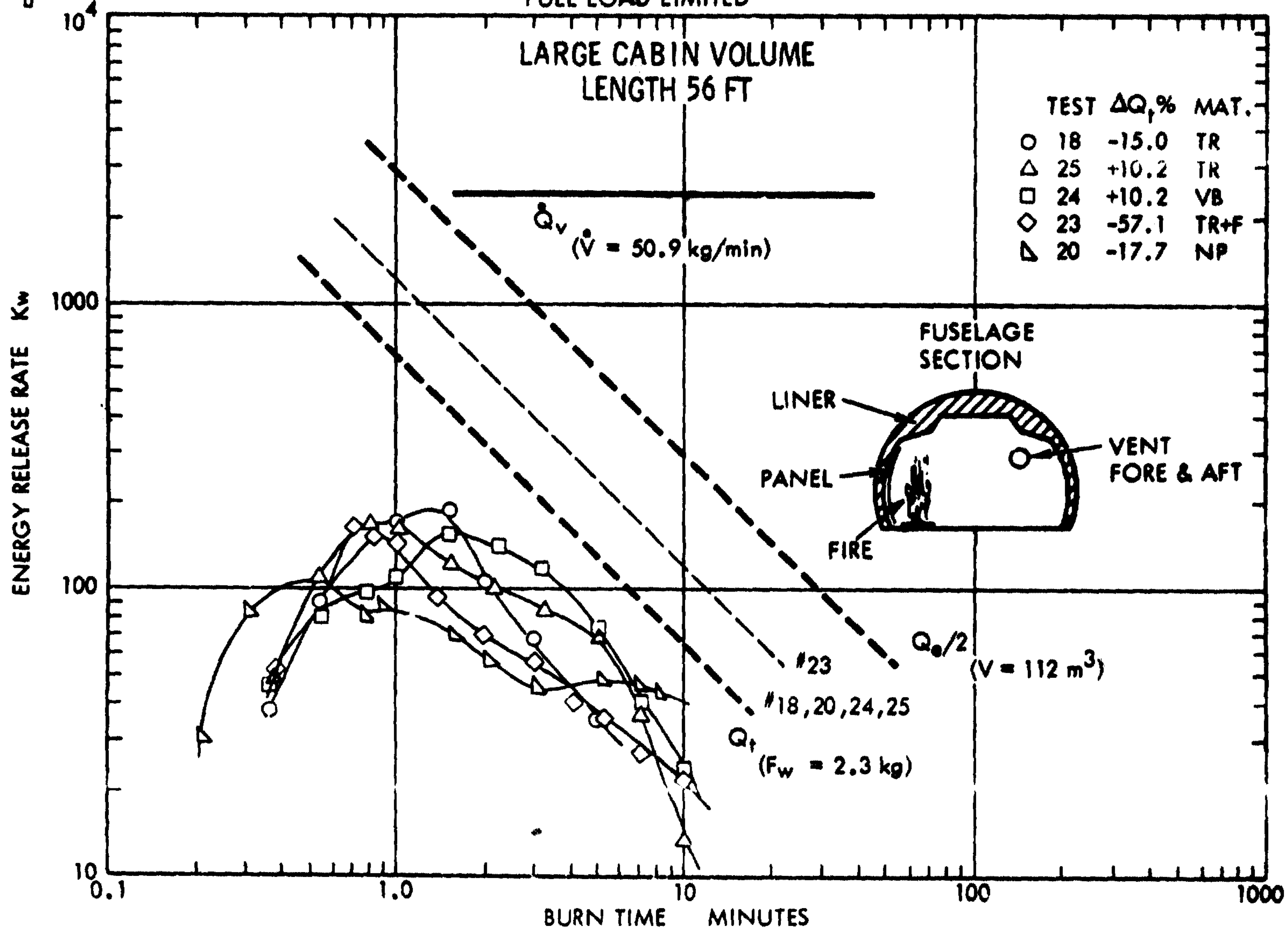


DATA VARIABILITY AND COMPARISON
LARGE FUEL PAN / SMALL CABIN VOLUME



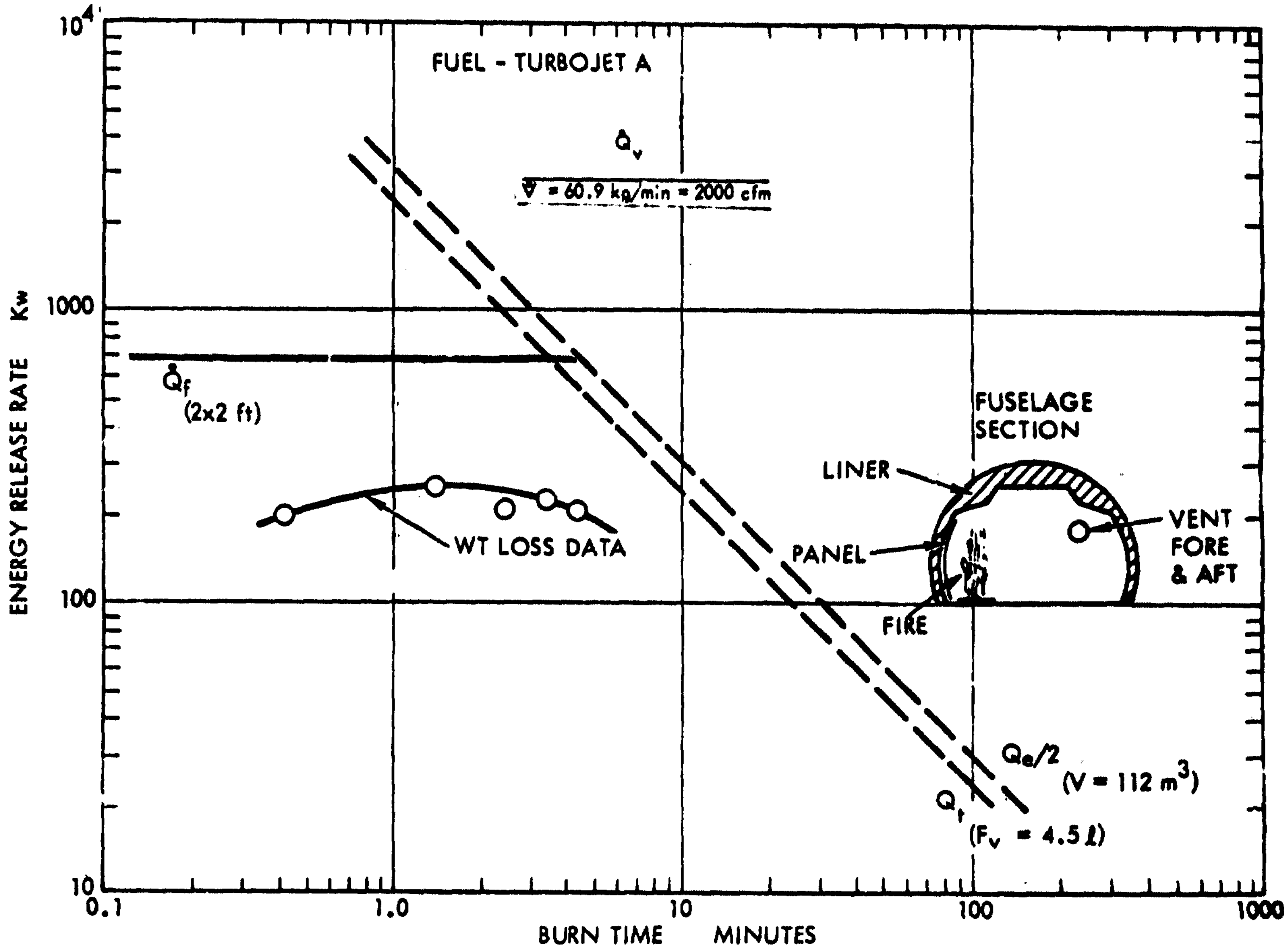
COMPARATIVE TRASH FUEL

FUEL LOAD LIMITED

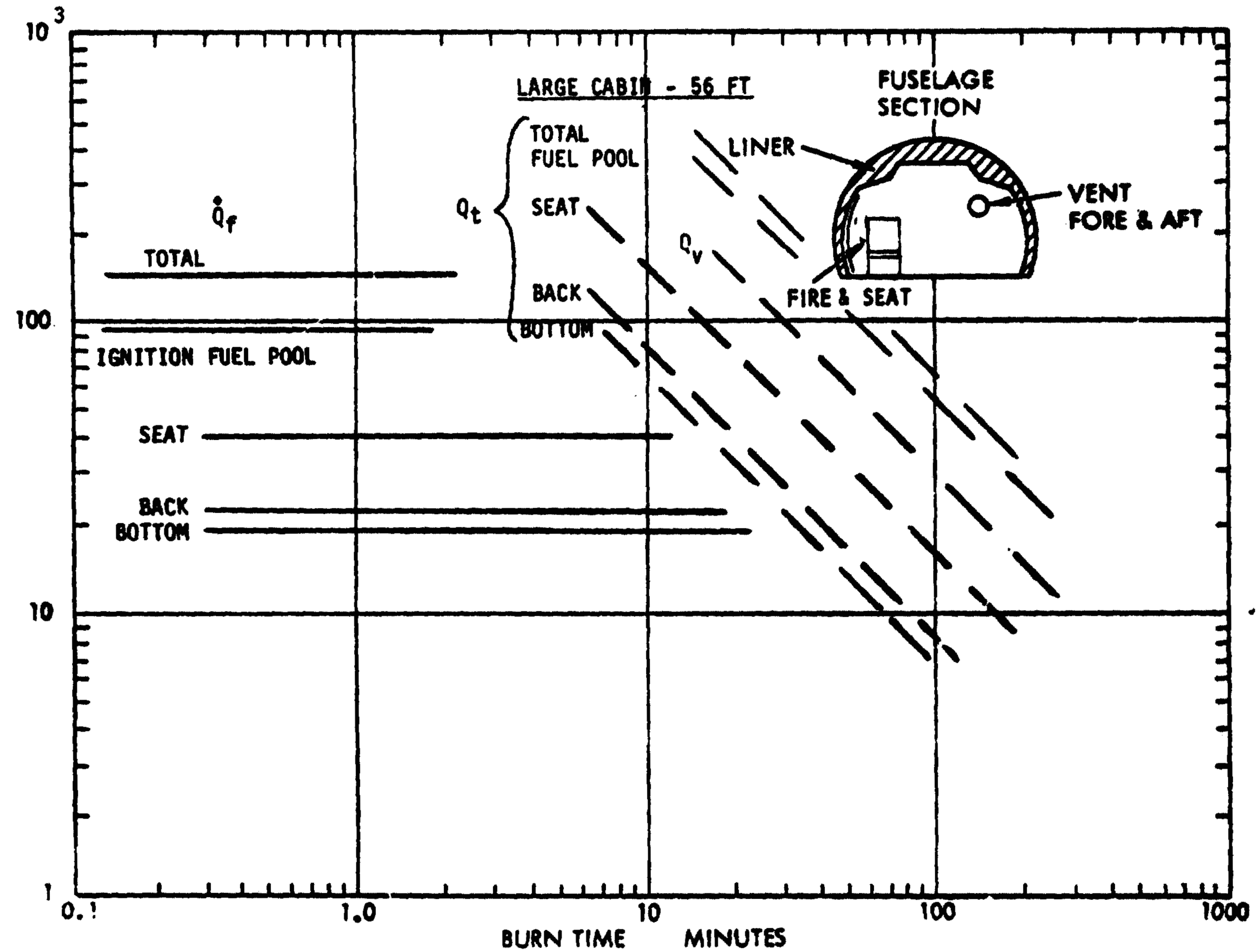


DATA VARIABILITY

LARGE FUEL PAN / LARGE CABIN VOLUME



CABIN SEAT LERC



CONCLUSIONS

- A COMPLETE LERC APPLICATION TO THE JSC/BOEING TESTS VERIFIES THE FUEL LOAD CRITERION AS THE CONSISTENT LIMITING CONSTRAINT

- THE VARIABILITY OF MAGNITUDE AND FORM OF THE RESULTS OF REPEATED TESTS WITH AND WITHOUT SMALL VARIATIONS IN PARAMETERS EMPHASIZES THE SIGNIFICANCE OF THE LOCAL FLOW, SPECIES-CONCENTRATION, AND HEAT-TRANSFER DISTRIBUTIONS

- WEIGHT-LOSS MEASUREMENTS OF RECENT JSC TESTS SHOW CONSISTENT RESULTS WITH PRIOR METHODS; FUEL LOAD CONSTRAINED

D7

N79-31173

ENCLOSURE FIRE DYNAMICS MODEL

505-08-25

JOSETTE BELLAN

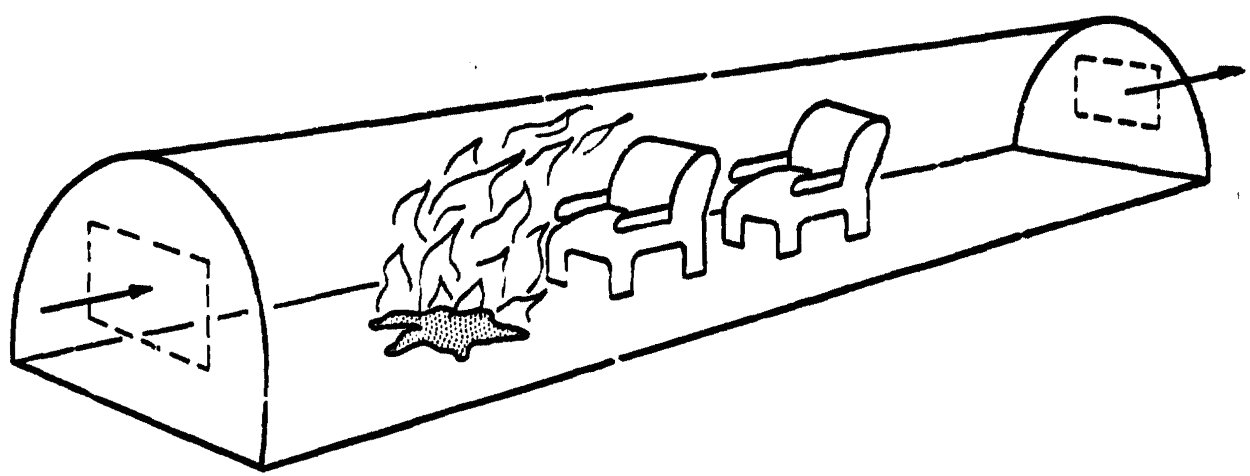
MARCH 1, 1979

ENCLOSURE FIRE DYNAMICS MODEL

PLAN OF THE PRESENTATION

1) PRACTICAL SITUATION. WHY A FIRE DYNAMICS MODEL?
2) DIFFICULTIES IN ESTABLISHING A MODEL.
3) BRIEF REVIEW OF ENCLOSURE-FIRE MODELS AVAILABLE.
4) OUR APPROXIMATION OF THE PRACTICAL SITUATION.
5) OUR MODEL.

PRACTICAL SITUATION



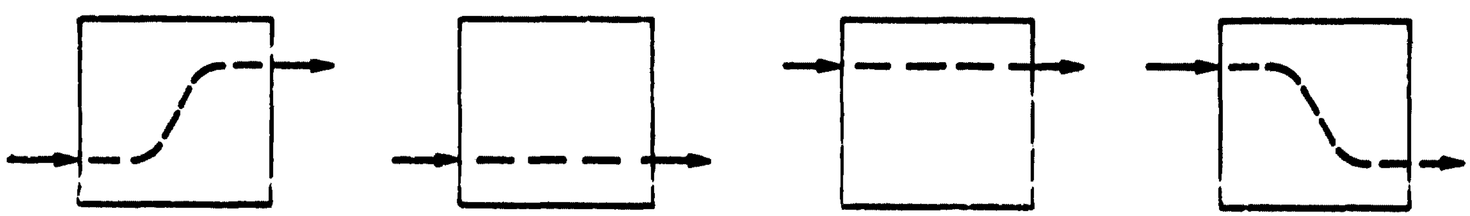
IT HAS BEEN SHOWN BY GLOBAL MODELING OF EXPERIMENTAL DATA THAT FIRE CAN BE LIMITED IN ITS PROPAGATION BY TWO FACTORS:

- LACK OF O_2 (VENTILATION, ENCLOSURE VOLUME)
- LACK OF FUEL (FUEL LOAD, FUEL SURFACE)

PRACTICAL SITUATION
(contd)

IT HAS ADDITIONALLY BEEN OBSERVED THAT:

- THE OUTCOME OF THE FIRE IS STRONGLY INFLUENCED BY VENTILATION PATTERNS



- THE OUTCOME OF THE FIRE IS STRONGLY INFLUENCED BY THE LOCATION OF THE FIRE
- THERE IS A STRONG TEMPERATURE CHANGE NOT ONLY IN THE HORIZONTAL, BUT ALSO IN THE VERTICAL DIRECTION DUE TO AIR BUOYANCY
- SURFACES, OTHER THAN THOSE BURNING, ARE FURTHER IGNITED DUE TO RADIATION AND/OR CONVECTION FROM THE EXISTING FIRE

GLOBAL MODELING CANNOT PREDICT THESE LATTER FIRE CHARACTERISTICS

→ A DETAILED ANALYTICAL MODEL IS NEEDED

DIFFICULTIES IN ESTABLISHING A MATHEMATICAL MODEL DESCRIBING FIRE IN AIRCRAFT

1) GEOMETRICAL ASPECTS
2) TURBULENT ASPECTS

   LACK OF DATA TO INDICATE LEVELS OF TURBULENCE TRANSPORT (cm^2/sec)
3) COMBUSTION ASPECTS

   LACK OF KNOWLEDGE ON THE DETAILED CHEMICAL MECHANISM. LACK OF DATA (E AND A) TO APPROXIMATE THOSE MECHANISMS BY A ONE STEP REACTION.
4) DESCRIPTION OF THE COUPLING BETWEEN COMBUSTION AND TURBULENCE
5) RADIATION ASPECTS

   VIEW FACTORS, EMISSIVITIES, GAS PHASE ABSORPTANCE AND TRANSMITTANCE
6) BOUNDARY CONDITIONS AND WALL EFFECTS

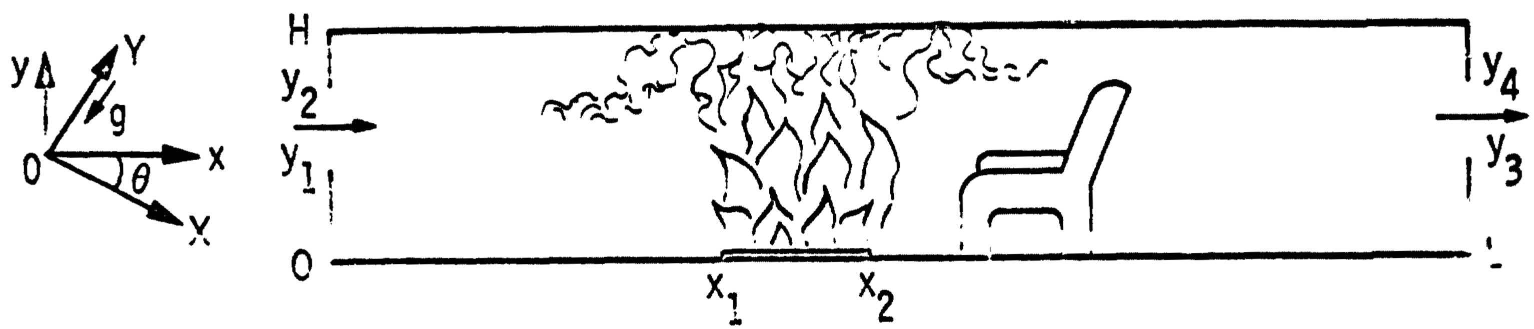
   DIFFICULT TO CORRECTLY APPROXIMATE BOTH WALL AND CORE PHENOMENA WITHIN REASONABLE CONSTRAINTS (MONEY, TIME, COMPUTER TIME)
7) LACK OF THERMOPHYSICAL AND THERMOCHEMICAL CONSTANTS FOR VARIOUS MATERIALS THAT ARE USED IN AIRCRAFT.

REVIEW OF ENCLOSURE — FIRE MODELS

	FIELD OR ZONE	CONSERVATION EQUATIONS					SURFACE IGNITION	COMBUSTION OF GASES	TURBULENCE	BOUNDARY CONDITIONS			RADIATION	PLUME MODEL	SPECIFIC DATA REQUIRED	PREDICTED QUANTITIES					
		MASS	MOM	ENERGY	GAS SPECIE	SMOKE				VENTILATION: NATURAL OR FORCED	VENTILATION: NO. OPENINGS	SURFACES				p	T_g	T_s	$\bar{V}$	SMOKE	SPECIES
EFDM	F (2-D)	✓	✓	✓	✓	LATER	LATER	P	EFFECTIVE TRANSPORT PROPERTIES	F/N	2	NO-SLIP VELOCITY; HEAT TRANSFER TO SURFACES; GASIFICATION OF FUEL	✓	N/A	THERMOPHYSICAL AND THERMOCHEMICAL PROPERTIES, STOICHIOMETRY	✓	✓	✓	✓	LATER	✓
NOTRE DAME	F (2-D)	✓	✓	✓					ALGEBRAIC MODEL (CORE AND WALL)	N	1,2	NO-SLIP VELOCITY; HEAT TRANSFER TO SURFACES	1-D MODEL: SOOT, H_2O, CO_2 BANDS	N/A	VARIOUS FUNDAMENTAL PHYSICAL PROPTIES; SPECIE AND SOOT CONCENTRATION	✓	✓	?	✓		
Mc DONNELL DOUGLAS	Z (3)	✓		✓	UK		UK	SE		UK	UK	HEAT TRANSFER TO SURFACES	BLACK BODY?		UK		✓	✓			UK
DAYTON	Z (3)	✓$_{-E}$	PLUME, CEILING JET ONLY	✓$_{-E}$	✓$_{-E}$	✓$_{-E}$	✓$_{-E}$	E		F/N	2	HEAT TRANSFER TO WALLS AND CEILING	ABSORBING AND EMITTING UPPER LAYER: FLAME RADIATION MODEL INCLUDING SOOT	FANG/ROCKET FLAME/PLUME MODEL; STEWARD MODEL IN BUOYANT PLUME	RATES AND TIMES GOVERNING TRANSITION STATES: HEAT RELEASE, SPECIE EVOLUTION, FLAME SPREAD		✓	✓		✓	O_2 CO HCN HCl SO_2, HF
IITRI	Z (2)	✓$_{-E}$		✓$_{-E}$			✓$_{-E}$	E		N	1	HEAT TRANSFER TO WALLS AND CEILING	BLACK BODY?	FANG's FLAME/PLUME MODEL	FUEL GASIFICATION RATES; COMBUSTION EFFICIENCY		✓	✓			
NBS	Z (4)	✓		✓				P		N	1	HEAT TRANSFER TO WALLS AND CEILING		STEWARD'S "TURBULENT DIFFUSION BUOYANT FLAME" MODEL	SOOT CONCENTRATION ΔH, GASIFICATION TEMPS, STOICHIOMETRY						
HARVARD	Z (2)	✓$_{-E}$		✓$_{-E}$				E		N	1	HEAT TRANSFER TO UPPER WALLS AND CEILING	?	MORTON'S "POINT-SOURCE" BUOYANT PLUME	BURNING RATES		✓	✓			

E - EMPIRICAL INPUT REQUIRED
SE - SEMI-EMPIRICAL
P - PREDICTED
NA - NOT APPLICABLE
UK - UNKNOWN

APPROXIMATION OF THE PRACTICAL SITUATION



MATHEMATICAL MODELING INCLUDES:

- WRITING THE CONSERVATION EQUATIONS FOR TURBULENT FLOW
- MODELING THE COMBUSTION TERMS IN THESE EQUATIONS
- MODELING THE RADIATION TERMS IN THESE EQUATIONS
- WRITING THE BOUNDARY CONDITIONS FOR A GIVEN SITUATION
- WRITING THE INITIAL CONDITIONS FOR A GIVEN SITUATION
- FINDING THE VALUE OF THE RELEVANT BASIC CONSTANTS THAT ARE RELATED TO MATERIAL PROPERTIES

THE CONSERVATION EQUATIONS
(1 of 3)

MASS

$$\underbrace{\frac{\partial \rho}{\partial t}}_{\text{transient term}} + \underbrace{\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y}}_{\text{convective terms}} = 0$$

x-MOMENTUM COMPONENT

$$\underbrace{\rho \frac{\partial u}{\partial t}}_{\text{transient term}} + \underbrace{\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y}}_{\text{convective terms}} = \underbrace{- \frac{\partial p}{\partial x}}_{\text{pressure change term}} \underbrace{- g \rho \sin \theta}_{\text{buoyancy term}} +$$

$$\underbrace{\frac{\partial}{\partial x}\left[\left(-\frac{2}{3}\mu_T\right)\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)\right] + 2\frac{\partial}{\partial x}\left(\mu_{x_T}\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left[\mu_{y_T}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right]}_{\text{viscous stress terms (turbulent)}}$$

THE CONSERVATION EQUATIONS
(2 of 3)

y-MOMENTUM COMPONENT

$$\underbrace{\rho\frac{\partial v}{\partial t}}_{\substack{\text{transient}\\ \text{term}}} + \underbrace{\rho u\frac{\partial v}{\partial x} + \rho v\frac{\partial v}{\partial y}}_{\text{convective terms}} = \underbrace{-\frac{\partial p}{\partial y}}_{\substack{\text{pressure}\\ \text{change}\\ \text{term}}} \underbrace{- g\rho\cos\theta}_{\substack{\text{buoyancy}\\ \text{term}}}$$

$$\underbrace{+\frac{\partial}{\partial x}\left[\mu_{x_T}\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right] + \frac{\partial}{\partial y}\left[\left(-\frac{2}{3}\mu_T\right)\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)\right] + 2\frac{\partial}{\partial y}\left[\mu_{y_T}\frac{\partial v}{\partial y}\right]}_{\substack{\text{viscous stress terms}\\ \text{(turbulent)}}}$$

SPECIES

$$\underbrace{\rho\frac{\partial Y_i}{\partial t}}_{\substack{\text{transient}\\ \text{term}}} + \underbrace{\rho u\frac{\partial Y_i}{\partial x} + \rho v\frac{\partial Y_i}{\partial y}}_{\text{convective terms}} = \underbrace{\frac{\partial}{\partial x}\left(D_{x_T}\,\rho\frac{\partial Y_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_{y_T}\,\rho\frac{\partial Y_i}{\partial y}\right)}_{\substack{\text{diffusive terms}\\ \text{(turbulent)}}} + \underbrace{\dot{\omega}_i}_{\substack{\text{source}\\ \text{or sink}\\ \text{term}}}$$

i = fuel, oxygen, nitrogen, water, carbon dioxide.

THE CONSERVATION EQUATIONS

(3 of 3)

ENERGY

$$\rho C_p \frac{\partial T}{\partial t} + \underbrace{\rho u \, C_p \frac{\partial T}{\partial x} + \rho v \, C_p \frac{\partial T}{\partial y}}_{\text{convective terms}} = \frac{\partial p}{\partial t} + \underbrace{\frac{\partial}{\partial x}\left(k_{x_T} \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_{y_T} \frac{\partial T}{\partial y}\right)}_{\text{conductive terms (turbulent)}}$$

transient term — convective terms — pressure change term — conductive terms (turbulent)

$$- g\rho v \quad + \quad \dot{Q}\rho \quad + \quad \dot{R}_{net}$$

work — source of heat due to combustion — radiation term

STATE

$$p = \rho RT \quad \text{with} \quad R = R_u \Sigma_i \frac{Y_i}{w_i}$$

MODELING OF COMBUSTION

$$C_n H_m + (n + \frac{m}{4}) O_2 \longrightarrow n\, CO_2 + \frac{m}{2} H_2O$$

$$\dot{\omega}_F = c_1 \dot{\omega}_{O_2} \qquad \text{with} \qquad c_1 = \frac{w_F}{w_{O_2}} \frac{1}{n + \frac{m}{4}}$$

$$\dot{\omega}_{CO_2} = -c_2 \dot{\omega}_{O_2} \qquad \text{with} \qquad c_2 = \frac{w_{CO_2}}{w_{O_2}} \frac{n}{n + \frac{m}{4}}$$

$$\dot{\omega}_{H_2O} = -c_3 \dot{\omega}_{O_2} \qquad \text{with} \qquad c_3 = \frac{w_{H_2O}}{w_{O_2}} \frac{m/2}{n + \frac{m}{4}}$$

$$\dot{\omega}_{O_2} = w_{O_2} \frac{d\,[O_2]}{dt} = -k_f \frac{1}{W_F} Y_F Y_{O_2} \rho^2 \quad \text{with} \quad k_f = Ae^{-E/RT}$$

$$\dot{Q} = \frac{1}{\rho} \left(c_1 h^0{}_F - c_2 h^0{}_{CO_2} - c_3 h^0{}_{H_2O} \right) \left(-\dot{\omega}_{O_2} \right)$$

BOUNDARY CONDITIONS

WALLS (INERT)

$u = 0 \quad , \quad v = 0$

$\dfrac{\partial Y_i}{\partial \vec{n}} = 0 \quad ;$ $\vec{n}$ is the direction perpendicular to the wall

thin wall assumption

$$\delta_w \rho_w C_w \frac{\partial T_w}{\partial t} = k_g \frac{\partial T}{\partial \vec{n}} + \dot{q}_{\underset{rad}{net}} + l \frac{\partial}{\partial \vec{s}} \left(k_{s_w} \frac{\partial T_w}{\partial \vec{s}} \right) \; ;$$

$\vec{s}$ is the direction along the wall;

$$l = \begin{cases} H \text{ if } \vec{n} = \vec{x} \\ L \text{ if } \vec{n} = \vec{y} \end{cases}$$

ENTRANCE $(x = 0, \; ; \; y_1 < y < y_2)$

$A \bar{\rho} \bar{u} = \dot{m}_{air}$ (forced ventilation)

$v = 0$

$\rho, T, Y_F, Y_{O_2}, Y_{N_2}, Y_{CO_2}, Y_{H_2O}$ given

BOUNDARY CONDITIONS (Cont'd)

EXIT $(x = L \; : \; y_3 < y < y_4)$

ρ, u, v, Y_F, Y_{O_2}, Y_{N_2}, Y_{CO_2}, Y_{H_2O}, T are found by forward extrapolation

POOL SURFACE $(y = 0 \; , \; x_1 < x < x_2)$

$$u = 0$$

$$\rho v \, Y_F - \rho D \frac{\partial Y_F}{\partial y} = \dot{M}_F$$

$$\rho v \, Y_i - \rho D \frac{\partial Y_i}{\partial y} = 0 \qquad i = O_2, N_2, CO_2, H_2O$$

$$\dot{M}_F = \alpha \, p_{atm} \left\{ e^{\frac{L_g}{R_u}\left(\frac{1}{T_b} - \frac{1}{T_l}\right)} - \frac{Y_F}{W_F} \frac{1}{\sum \frac{Y_i}{W_i}} \right\} \left(\frac{W_F}{2\pi \tilde{R} T_l} \right)^{1/2}$$

thin wall assumption

$$\delta_l \, \rho_l C_l \frac{\partial T_l}{\partial t} = k_g \frac{\partial T}{\partial y} + \dot{q}_{\substack{net \\ rad}} - \dot{M}_F L_g$$

PRESENT AND FUTURE WORK

1) MODEL THE RADIATION TERMS
   - IN THE ENERGY EQUATION
   - IN THE BOUNDARY CONDITIONS
2) ENCODE THE EQUATIONS
   - SELECT A COMPUTATION SCHEME
   - TRANSFORM THE EQUATIONS FROM A DIFFERENTIAL TO A FINITE FORM
   - DEVELOP A COMPUTER CODE
3) ASCERTAIN THERMOPHYSICAL AND THERMOCHEMICAL CONSTANTS THAT ARE RELEVENT TO AIRCRAFT MATERIALS
4) CHARACTERIZE THE FLOW CONDITIONS IN AIRCRAFT (LEVELS OF TURBULENCE) USING AVAILABLE EXPERIMENTAL DATA

74 D8

N79-31174

LARGE–SCALE POOL FIRE TEST RECOMMENDATIONS

FIREMEN
FIRE MODELING AND SCALING METHODS
510–56–05

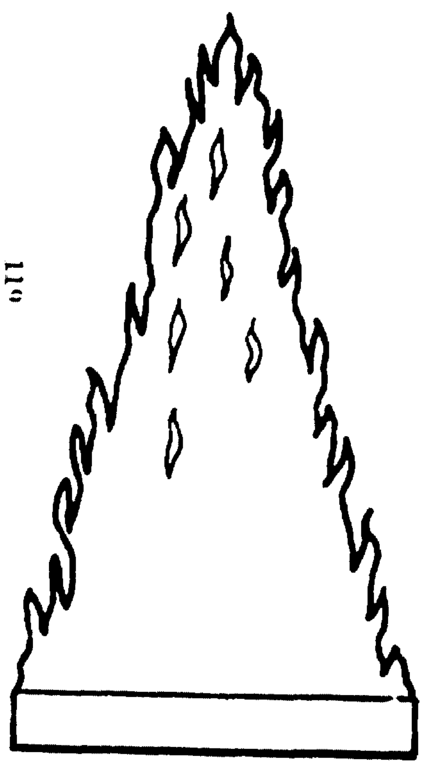
C. Perry Bankston

February 26, 1979

IMPORTANT ASPECTS OF EXTERNAL POOL FIRES

- HEAT TRANSFER
  - CONVECTIVE
  - RADIATIVE
- FLAME CHARACTERISTICS
  - BURNING RATES
  - FLAME SHAPE, SIZE
  - TURBULENCE
  - WIND EFFECTS
- PLUME CHARACTERISTICS
  - ENTRAINMENT
  - TURBULENCE
  - WIND EFFECTS
- UNSTEADY PHENOMENA
  - FIRE OSCILLATIONS
  - FIRE WHIRLS

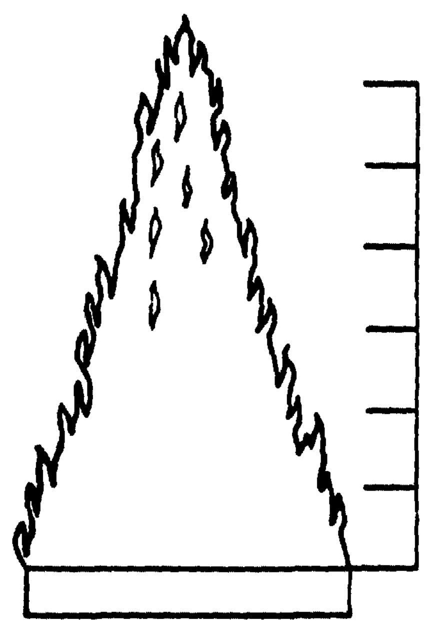
OBJECTIVES



- DETERMINE HEAT FLUX TO SURFACES AS A FUNCTION OF POOL SIZE
  - CONVECTIVE HEAT FLUX
  - RADIATIVE HEAT FLUX
- OBTAIN INFORMATION THAT CAN BE COMPARED WITH THEORETICAL MODEL FOR RADIATIVE FLUX IN THE 'NEAR FIELD'

→ PREDICT RADIATIVE HEAT FLUX FOR ARBITRARY POOL SIZE

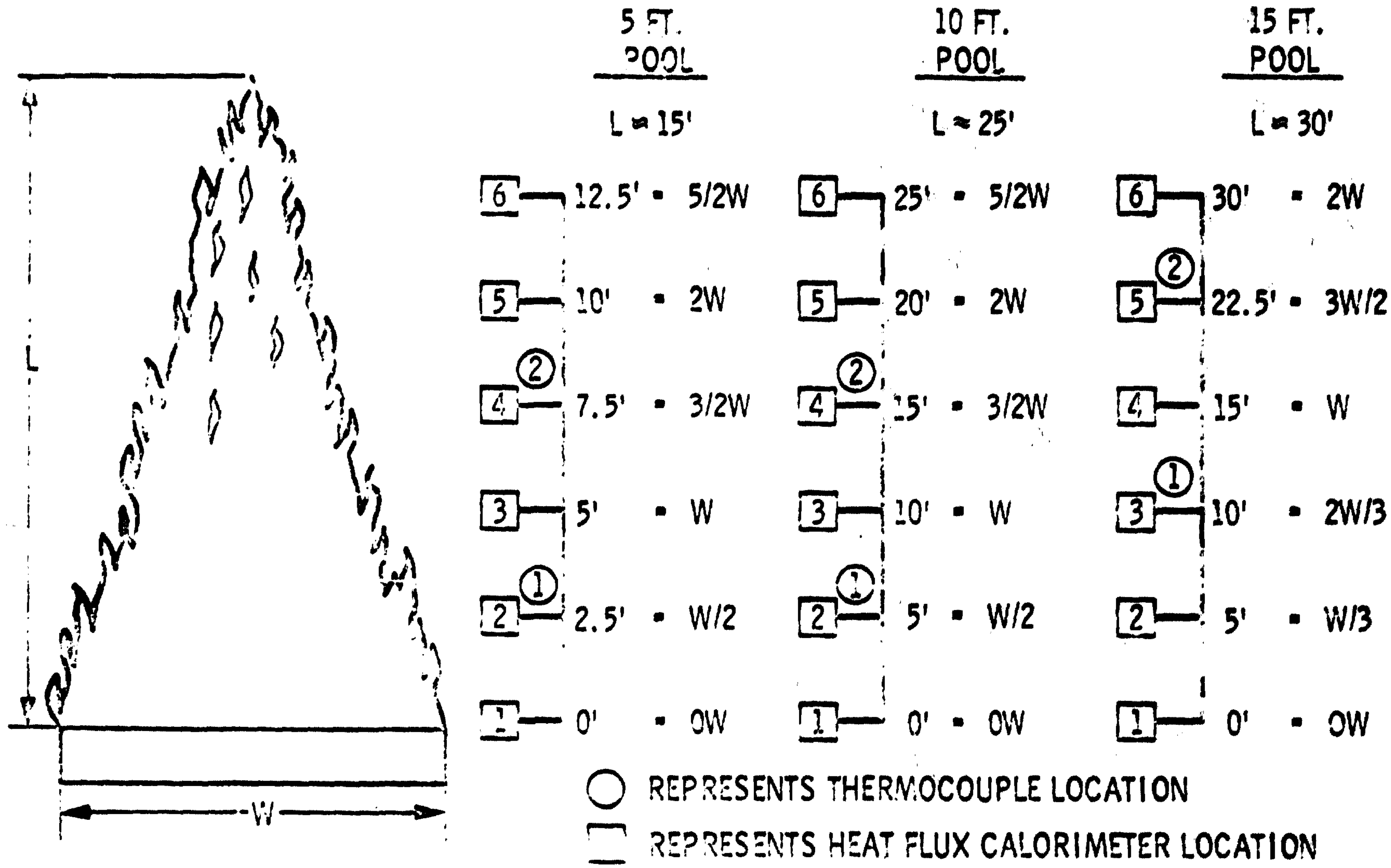
MEASUREMENTS AND INSTRUMENTATION:



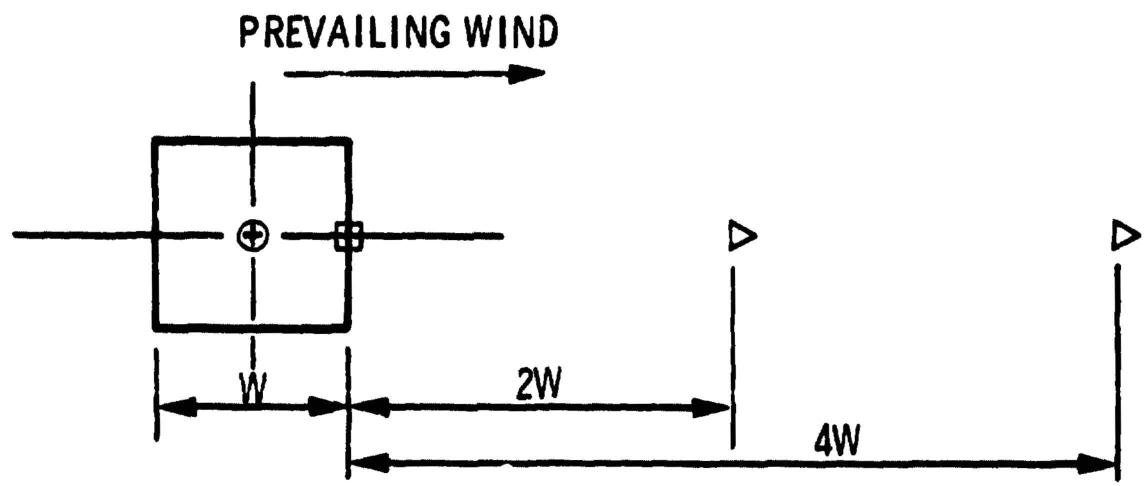
—OPEN POOL FIRES—

- HEAT FLUX: CALORIMETERS, RADIOMETERS
- TEMPERATURE: THERMOCOUPLES
- FLAME SIZE, SHAPE: PHOTOGRAPHY
- WEATHER ENVIRONMENT

VERTICAL POSITIONING OF NEAR-FIELD HEAT FLUX CALORIMETERS AND THERMOCOUPLES



LOCATION OF POOL FIRE INSTRUMENTATION (PLAN VIEW)

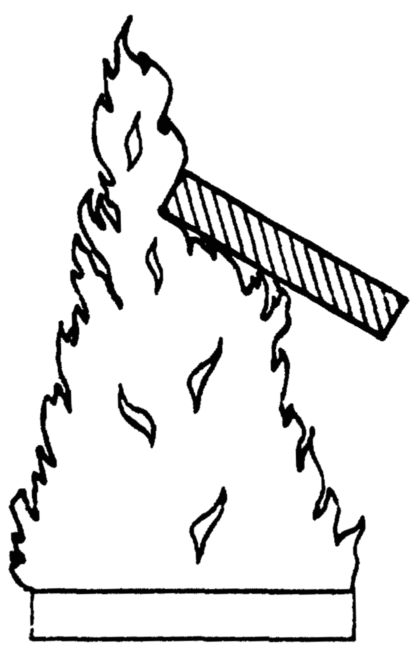


○ IN-THE-FLAME CALORIMETER AND THERMOCOUPLE (DIRECTED DOWN AT HEIGHT OF 0.6L)

□ NEAR-FIELD CALORIMETER/THERMOCOUPLE TREE

▷ FAR-FIELD RADIOMETERS

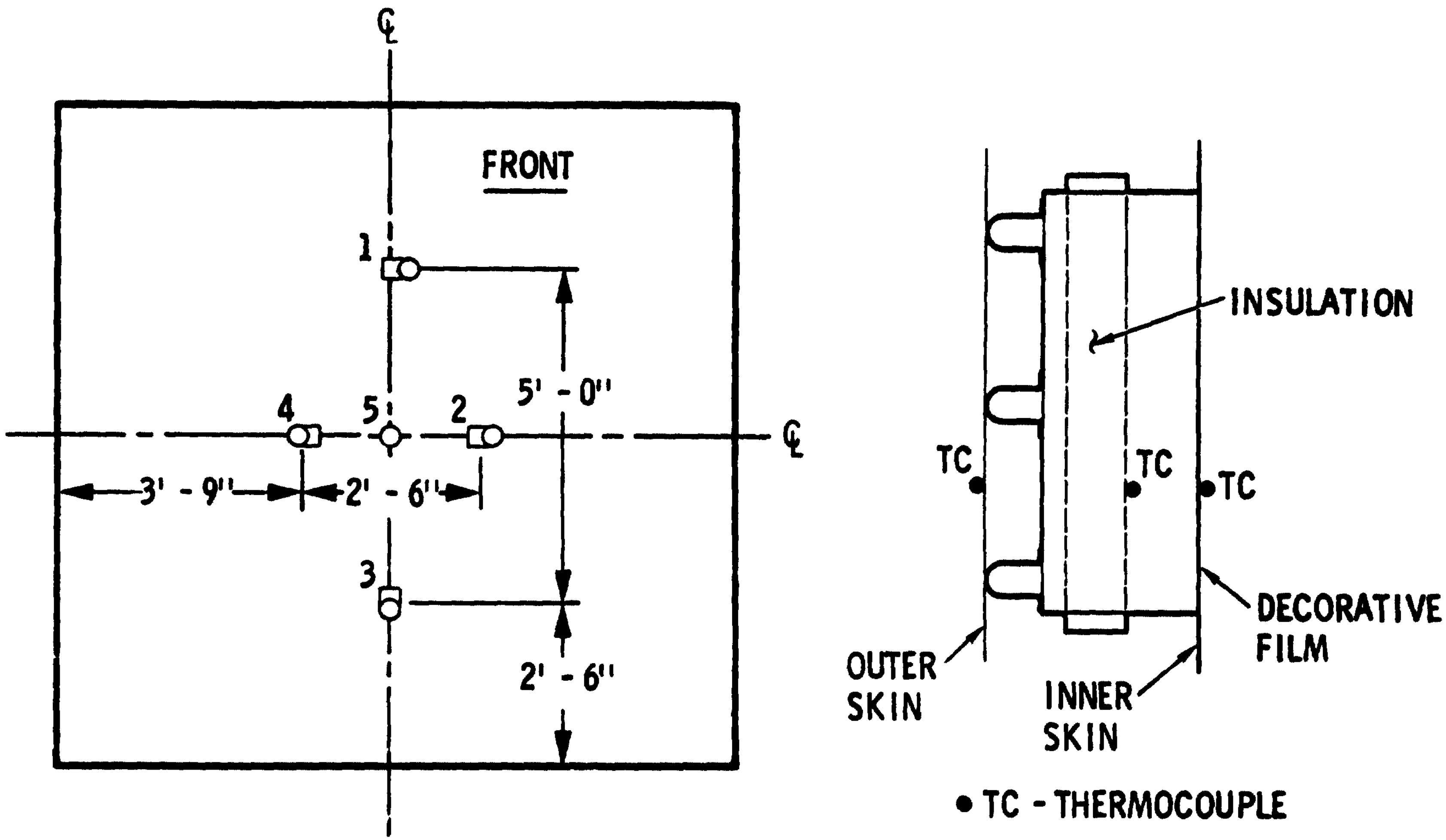
MEASUREMENTS AND INSTRUMENTATION:



—— 10 FT. X 10 FT. PANELS ——

- HEAT FLUX: CALORIMETERS
- TEMPERATURE (GAS, SURFACES): THERMOCOUPLES
- FLAME SIZE, SHAPE: PHOTOGRAPHY
- WEATHER ENVIRONMENT

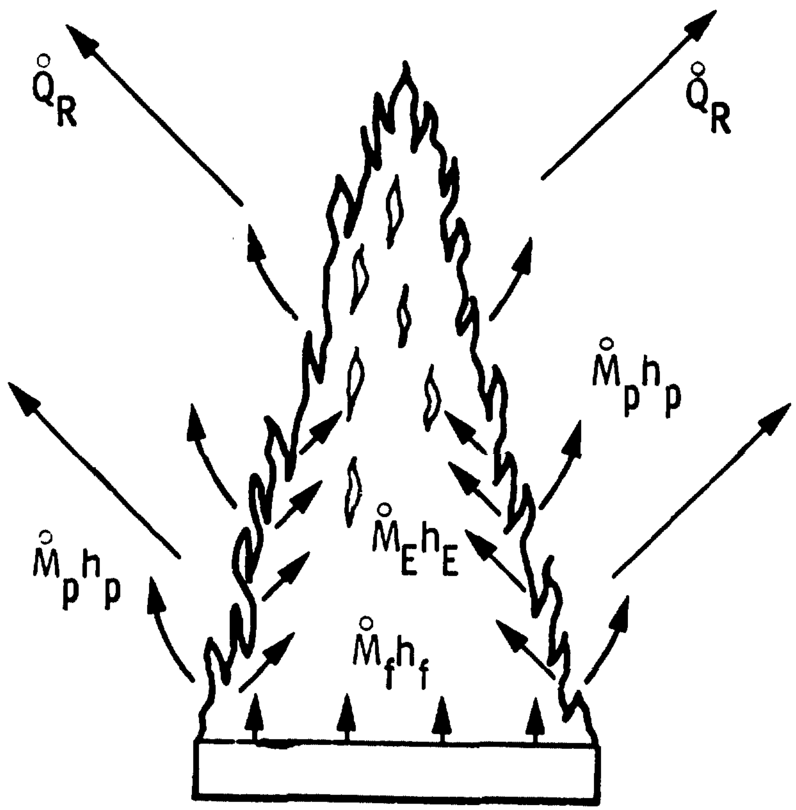
10 FT X 10 FT PANEL INSTRUMENTATION



○- THERMOCOUPLE

□- HEAT FLUX CALORIMETER

POOL FIRE FLAME HEAT BALANCE



ENERGY IN:

$$\mathring{M}_F h_F + \mathring{M}_E h_E + \beta \mathring{M}_F \Delta H$$

FUEL ENTRAINED AIR COMBUSTION

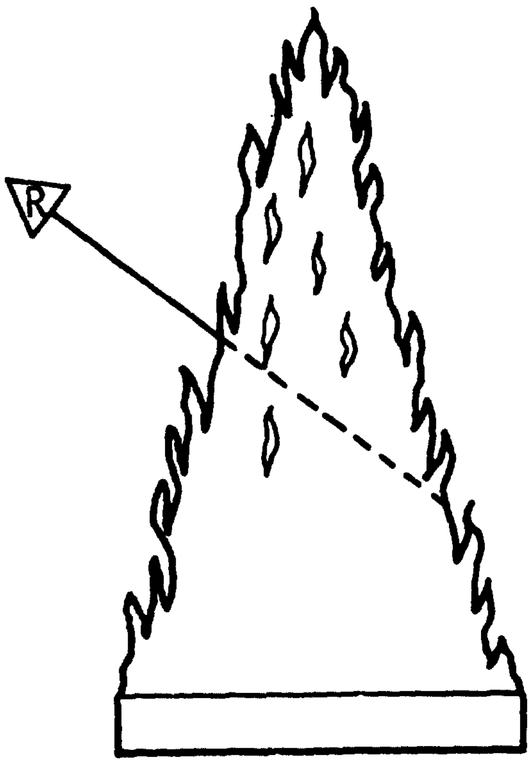
EQUALS

ENERGY OUT:

$$\mathring{Q}_{R_{TOT}} + \mathring{M}_p h_P$$

RADIATION COMBUSTION PRODUCTS

RADIATIVE HEAT TRANSFER MODELING



- HOMOGENEOUS, ISOTHERMAL ASSUMPTION
  INPUT: FLAME SHAPE
  FLAME TEMPERATURE
  EMISSIVITY
  OUTPUT: SPATIAL DISTRIBUTION OF
  RADIATION IN THE NEAR-FIELD

- NON-HOMOGENEOUS CASE (DETAILED FLAME MODEL)
  INPUT: THERMOCHEMICAL PROPERTIES
  BOUNDARY CONDITIONS
  OUTPUT: FLAME SHAPE, TEMPERATURE, EMISSIVITY
  BURNING RATE, ETC
  SPATIAL DISTRIBUTION OF RADIATION
  IN THE NEAR FIELD

D9

N79-31175

FUSELAGE VENTILATION UNDER WIND CONDITIONS

FIRE MODELING AND SCALING METHODS
510-56-05

Jay Wm. Stuart

OBJECTIVES

- DETERMINE REALISTIC FUSELAGE VENTILATION RATES FOR POST-CRASH FIRES AND FULL-SCALE FIRE TESTS

- FIND EFFECTS ON WIND-ABOUT-FUSELAGE VENTILATION RATE OF VARIOUS PARAMETERS

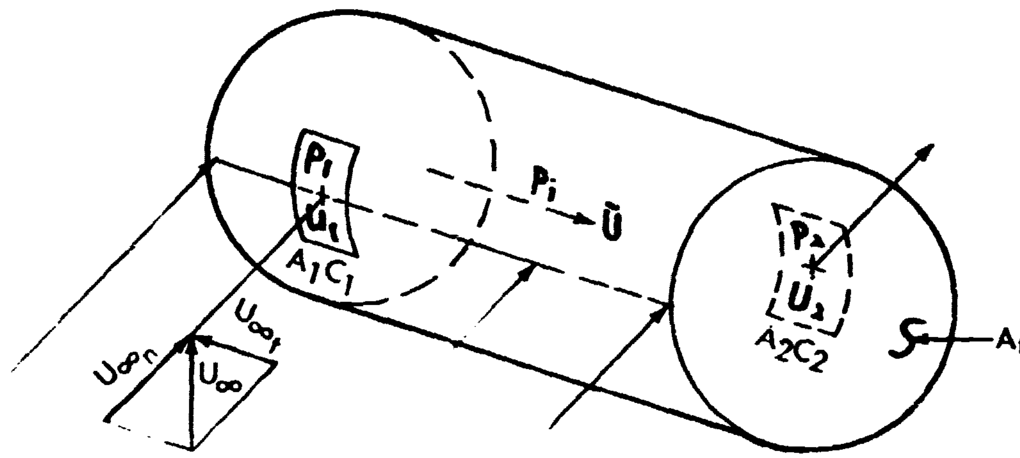
  FUSELAGE SIZE & SHAPE

  FUSELAGE ORIENTATION & PROXIMITY TO GROUND

  FUSELAGE-OPENINGS SIZE & LOCATION

  WIND SPEED & DIRECTION

FLUID MECHANICS OF FUSELAGE VENTILATION



FROM MASS CONTINUITY AND ASSUMING $d\rho = 0$

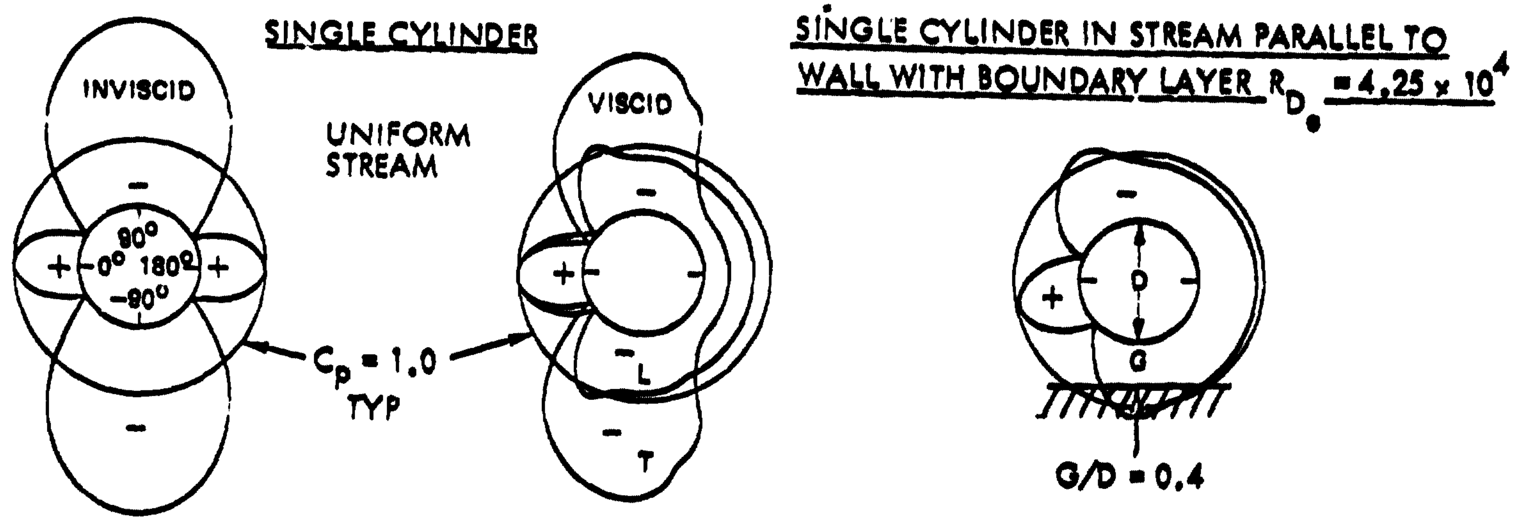
SOLVE $U_1A_1 = U_2A_2$ OR $A_1C_1\sqrt{2(p_1 - p_i)/\rho} = A_2C_2\sqrt{2(p_i - p_2)/\rho}$

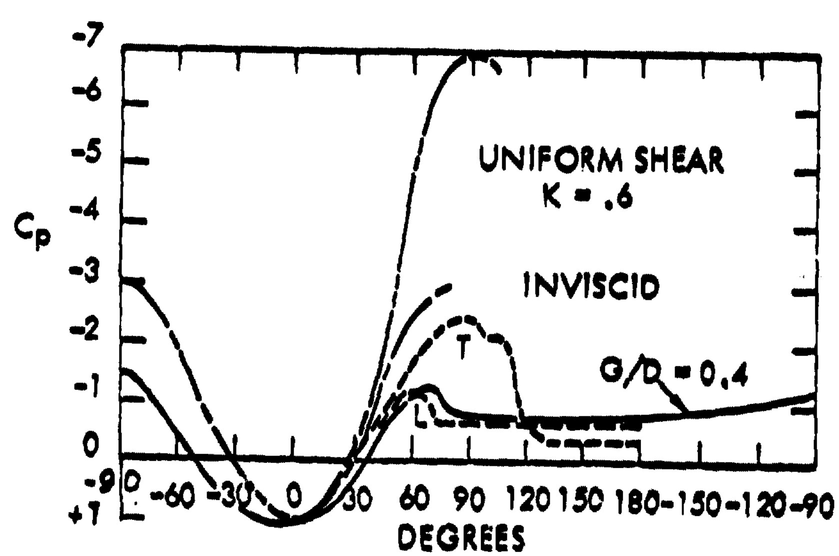
LETTING $C_p = p/q$, $q = \frac{\rho}{2} U_{\infty_n}^2$

<u>VOLUMETRIC RATE</u> $Q = C_1A_1U_{\infty_n}\sqrt{C_{p_1} - \left[C_{p_1} + C_{p_2}\left(\frac{A_2C_2}{A_1C_1}\right)^2\right] \Big/ \left[\left(\frac{A_2C_2}{A_1C_1}\right)^2 + 1\right]}$

<u>INTERIOR VENTILATION SPEED</u> $\bar{U} = Q/A_f$

PRESSURE DISTRIBUTIONS FOR FLOWS AROUND INFINITE CIRCULAR CYLINDERS





REFERENCES FOR PRESSURE DISTRIBUTIONS AROUND CIRCULAR CYLINDERS

1. Forrest E. Gowen and Edward W. Perkins, "Drag of Circular Cylinders for a Wide Range of Reynolds Numbers and Mach Numbers", NACA TN-2960, June 1953

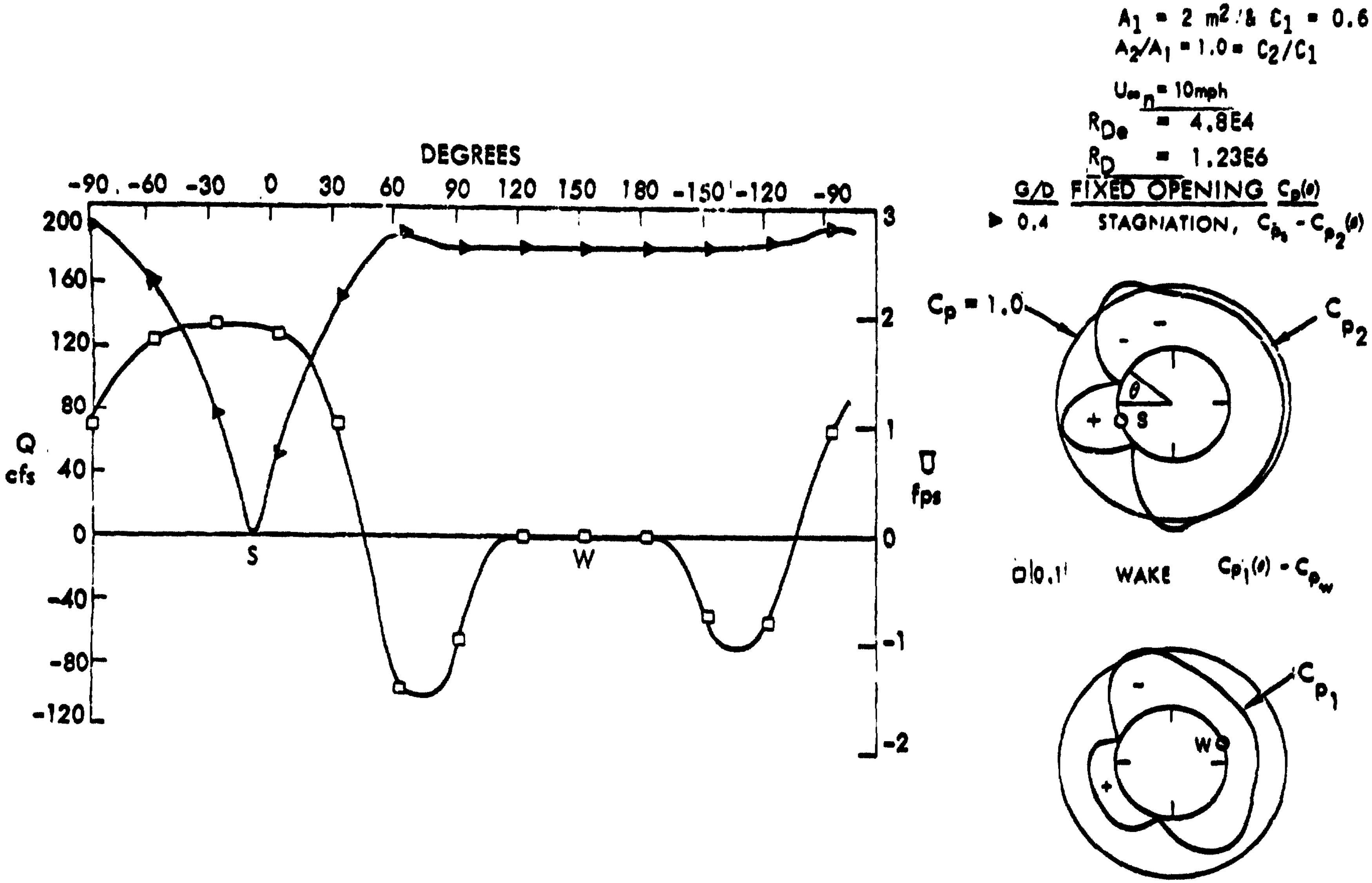
2. Melvin H. Snyder Jr., "Testing of Cylinders in Sheared Flow", J. Aircraft, Vol. 8, August 1971

3. P. W. Bearman and A. J. Wadcock, "Ther Interaction Between a Pair of Circular Cylinders Normal to a Stream", J. Fluid Mech. (1973), Vol. 61, Part 3, pp. 499-511

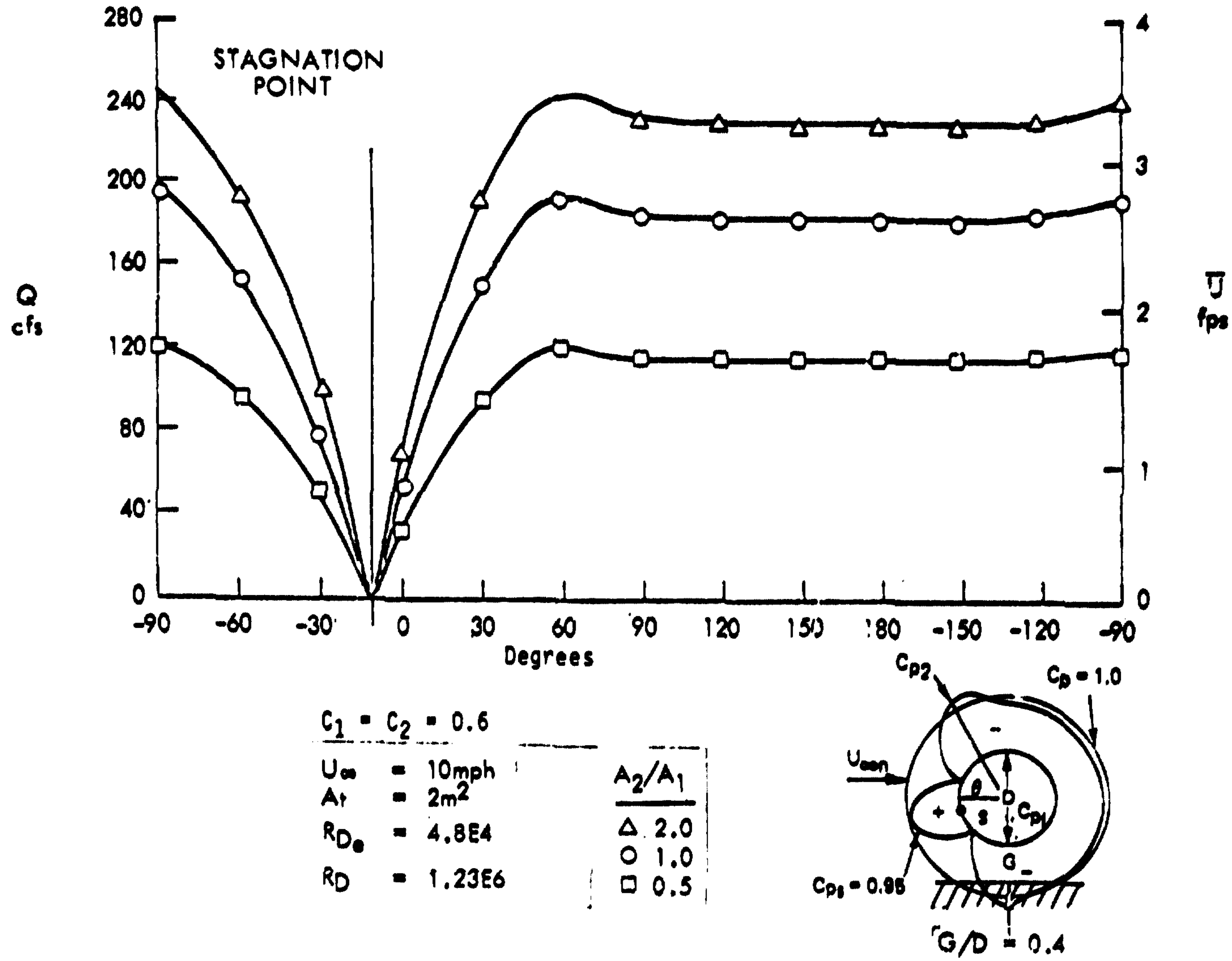
4. P. W. Bearman and M. M. Zdravkovich, "Flow Around a Circular Cylinder Near a Plane Boundary", J. Fluid Mech. (1978), Vol. 89, Part 1, pp. 33-47

VENTILATION PERFORMANCE COMPARISON

FIXED OPENINGS



VENTILATION PERFORMANCE
IN 2-DIM. FLOW OVER FUSELAGE



RECOMMENDATIONS

- CONDUCT JSC FULL-SCALE FIRE TESTS TO VALIDATE THE ESTIMATES OF FUSELAGE VENTILATION OF THIS ANALYSIS

- FOR THE REAL WIND-ABOUT-FUSELAGE CONDITIONS EXPERIMENTALLY DETERMINE VENTILATION RATES APPLICABLE TO POST-CRASH FIRES & FULL-SCALE FIRE TESTS

    WIND SPEED & DIRECTION

    FULL-SCALE REYNOLDS NUMBERS

    FUSELAGE SHAPE

    FUSELAGE ORIENTATION & PROXIMITY TO GROUND

    FUSELAGE-OPENINGS SIZE & LOCATION

    FIRE-CONVECTION INDUCED SPEED OR CIRCULATION

D10

N79-31176

FIRE RESISTANT AIRCRAFT SEAT PROGRAM

PRESENTED

AT

JOINT NASA/INDUSTRY STEERING GROUP UPDATE AND REVIEW MEETING March 1 & 2, 1979

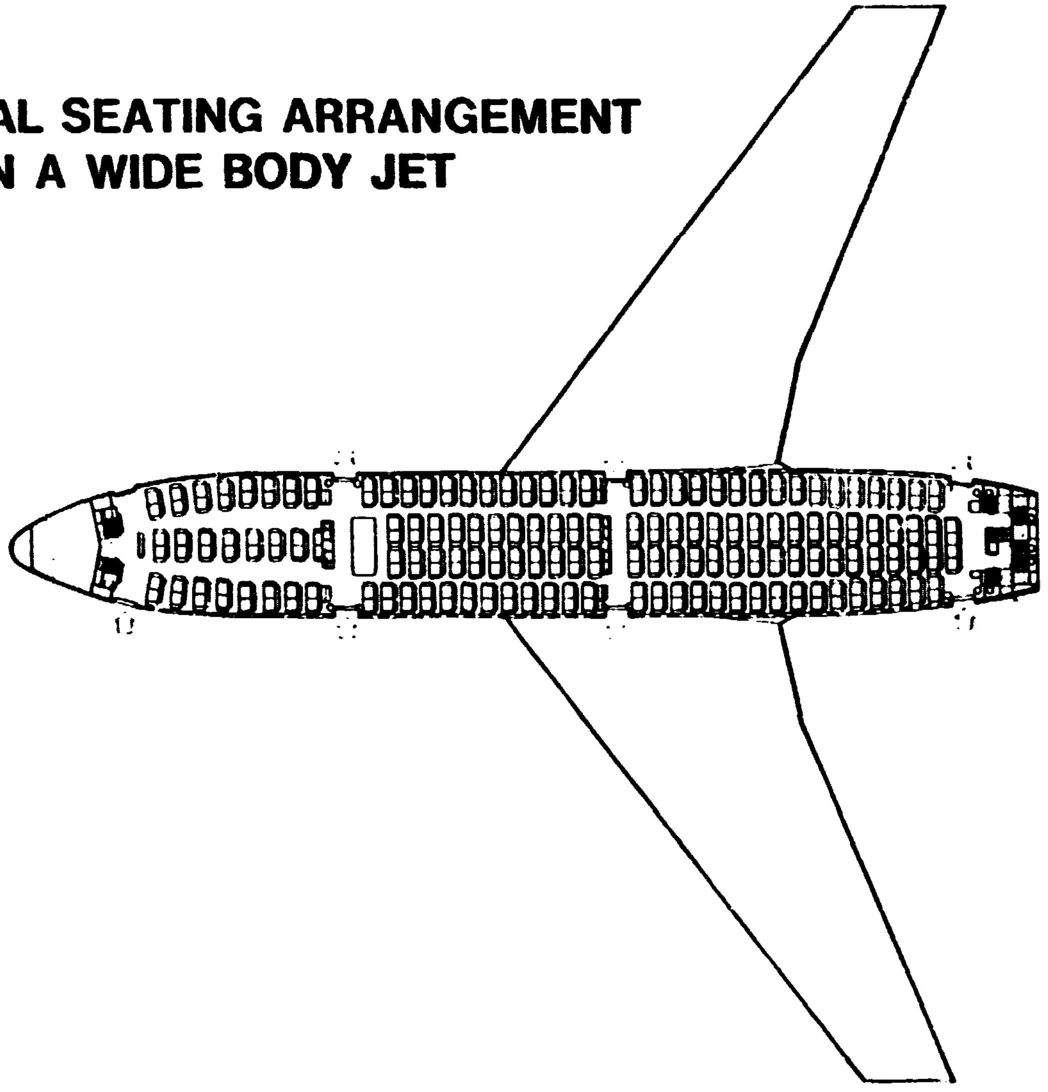
Larry L. Fewell

Project Director

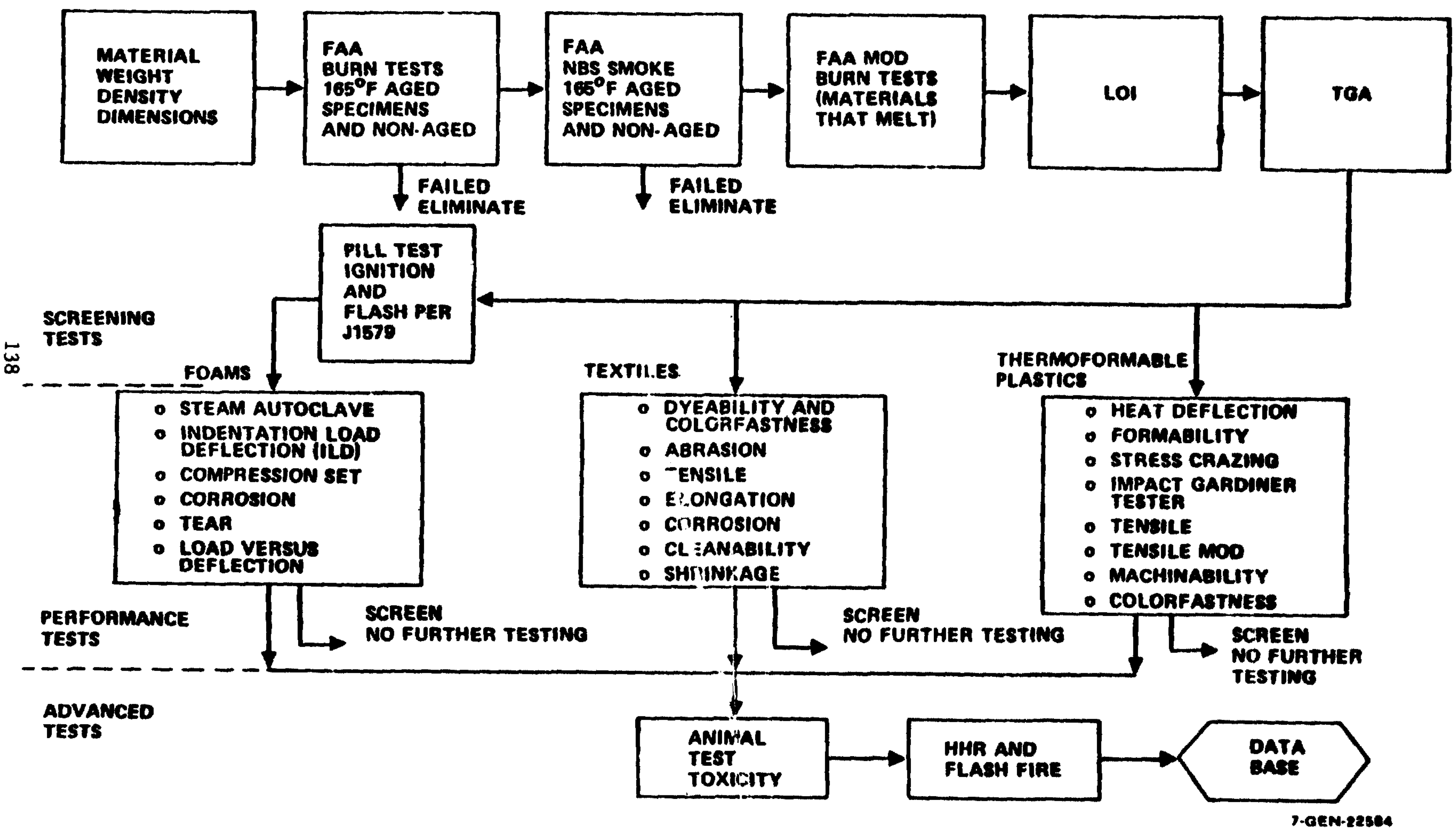
FIRE RESISTANT AIRCRAFT SEAT MATERIALS

LARRY L. FEWELL
PROJECT DIRECTOR

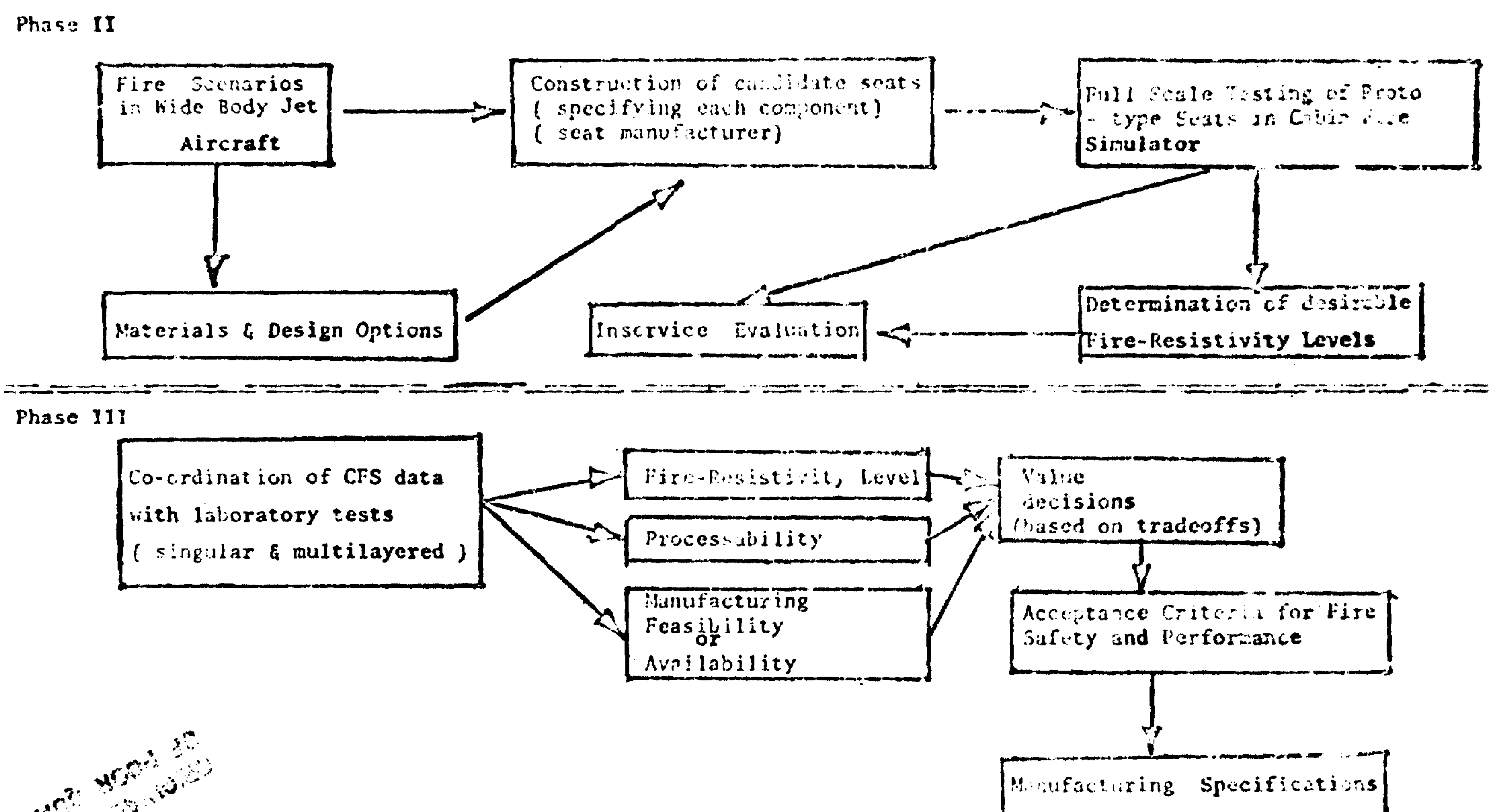
TYPICAL SEATING ARRANGEMENT ON A WIDE BODY JET



PHASE I MATERIAL TEST PROGRAM



FIRE - SAFE AIRCRAFT SEAT PROGRAM



CANDIDATE MATERIALS TESTED

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
100	ST7193-29	100% NYLON, AIRGARD TREATED 11.4-12.6 OZ/YD^2 LANDSCAPE FABRIC	LANDSCAPE	COLLINS & AIKMAN CORP.
101	20787	52.5% KERMEL/47.5% WOOL 277 gm/m^2	–	H. LELIEVRE, PARIS
102	OL618	100% COTTON DOUBLEKNIT 10 ± 5% OZ/YD^2 (LI SPEC 33)	–	LANGENTHAL INTERNATIONAL CORP.
103	69-407	100% NOMEX 8.4-9.7 OZ/YD^2 TULSA (DRAPERY FABRIC)	TULSA	COLLINS & AIKMAN CORP.
*104	ST7427-112	90% WOOL/10% NYLON FABRIC 12.2 TO 14.0 OZ/YD^2 SUN ECLIPSE	SUN ECLIPSE	COLLINS & AIKMAN CORP.
105	7979	50% KYNOL/50% NOMEX 10.7 OZ/YD^2 FABRIC	"NO BURN" FABRIC	COLLINS & AIKMAN CORP.
106	NYLON GOLD 1902	NYLON GOLD/VONAR 3 NEOPRENE FOAM BACKING	–	DUPONT DE NEMOURS
107	URETHANE COATED NYLON	URETHANE ELASTOMER COATED NYLON FABRIC	–	REEVES BROTHERS
108	NO. 300 COTTON KNIT FABRIC	COTTON KNIT FABRIC, COLOR 23 JASMIN	–	LANGENTHAL INTERNATIONAL CORP.
109	NO. 340 COTTON KNIT FABRIC	COTTON KNIT FABRIC SQUARE KNIT	–	LANGENTHAL INTERNATIONAL CORP.
110	2069	KERMEL 39%/WOOL 61%, COLOR 2 ROUX FABRIC 575 g/m^2	–	H. LELIEVRE, PARIS

CANDIDATE MATERIALS TESTED (CONT'D)

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
200	NO. 24	100% KYNOL FABRIC TWILL WEAVE	KYNOL	AMERICAN KYNOL, INC
201	NO. 1110	70% KYNOL/30% NOMEX PERMANENT PRESS FINISH 6.2 OZ/YD^2	KYNOL	AMERICAN KYNOL, INC
202	NO. 1090	70% KYNOL 30% NOMEX 4.6 OZ/YD^2 WITH PERMANENT PRESS FINISH	KYNOL	AMERICAN KYNOL INC
203	B-104S	100% KYNOL BATTING ON POLYESTER SCRIM-NEEDLE PUNCH	KYNOL	AMERICAN KYNOL, INC
204	40-9010-1	PBI FABRIC NATURAL UNSTABILIZED 5.1 OZ/YD^2 2 x 1 TWILL	–	CELANESE FIBERS MARKETING CO.
205	40-4010-1	PBI BATTING 4 OZ/YD^2 NATURAL UNSTABILIZED FROM STAPLE	–	CELANESE FIBERS MARKETING CO.
206	35-4020-1	BLACK BATTING 4 OZ/YD^2 (PROPRIETARY)	–	CELANESE FIBERS MARKETING CO.
207	KYNOL ON REMAY SCRIM BATTING	REMAY SPUN BONDED POLYESTER FABRIC NEEDLED WITH 100% KYNOL FIBER [illegible].8 OZ/YD^2	"FLAMEOUT"	DAN RIVER, INC
208	NEOPRENE FOAM	1/16 IN. NEOPRENE FOAM WITH 1-2 OZ/YD^2 COTTON SCRIM	VONAR NO. 1 INTERLINER	DUPONT DE NEMOURS
209	NEOPRENE FOAM	2/16 IN. NEOPRENE FOAM WITH 1-2 OZ/YD^2 COTTON SCRIM	VONAR NO. 2 INTERLINER	DUPONT DE NEMOURS

CANDIDATE MATERIALS TESTED (CONT'D)

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
210	NEOPRENE FOAM	3/16 IN. NEOPRENE FOAM WITH 1-2 OZ/YD^2 COTTON SCRIM	VONAR NO. 3 INTERLINER	DUPONT DE NEMOURS
211	NYLON GOLD 1902	SEE NO. 108		
212	UPHOLSTERY FABRIC	DURETTE UPHOLSTERY FABRIC	DURETTE	FIRE SAFE PRODUCTS
213	SE5559	ELASTOMER, SILICONE RUBBER S.G. 1.33	–	GENERAL ELECTRIC (WATERFORD, NY)
214	NOMEX III	ARAMID FABRIC	NOMEX III	DUPONT DE NEMOURS & CO.
215	KERMEL	KERMEL FABRIC 250 gm/m^2 AMIDE-IMIDE	KERMEL	RHODIA, INC
216	400-11	DURETTE BATTING	DURETTE	FIRE SAFE PRODUCTS
217	400-6	DURETTE DUCK 4.4 OZ/YD^2	DURETTE	FIRE SAFE PRODUCTS
218	410-13	DURETTE DUCK BLACK	DURETTE	FIRE SAFE PRODUCTS
219	400-37	DURETTE TWILL	DURETTE	FIRE SAFE PRODUCTS

CANDIDATE MATERIALS TESTED (CONT'D)

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
220	35-4025	PREOXIDIZED BATTING 400-8		CELANESE FIBER MARKETING CO
221	S470	NOMEX III DUAL FABRIC, NATURAL 7.5 OZ/YD^2		SOUTHERN MILLS, INC SENOIA, GA
222	40-9031-2	WOVEN PBI FABRIC HEAT STABILIZED 4.2 OZ/YD^2, 2 x 1 TWILL MADE FROM THERMALLY STABILIZED PBI YARN		CELANESE FIBER MARKETING CO

CANDIDATE MATERIALS TESTED (CONT'D)

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
300	FG215	GLASS FIBER BLOCK CUSHION EDGE GRAIN BLOCKING OF GLASS FIBERS	–	EXPANDED RUBBER AND PLASTICS CORP.
301	R-207080	APN PHOSPHAZENE OPEN CELL FOAM 0.14 g/cc	APN FOAM	FIRESTONE TIRE & RUBBER CO.
302	9907-13	URETHANE FOAM, FLEXIBLE	HYPOL	W. R. GRACE & CO.
303	EXP1408	SILICONE RUBBER SPONGE 11 LB/FT^3	–	KIRKHILL RUBBER COMPANY
304	14183-B	SILICONE RUBBER SPONGE 11.8 LB/FT^3	MOSITES	MOSITES RUBBER CO., INC.
305	NO. 510	SILICONE RUBBER SPONGE 0.21 gm/cc	–	SILICONE ENGINEERING LTD. ENGLAND
*306	H-45C	URETHANE FOAM 0.03 gm/cc	–	E. R. CARPENTER CO., INC
307	HL1-7-77	NEOPRENE FOAM, OPEN CELL	–	TOYAD CORP.
308	KAYLON FIRM	NEOPRENE FOAM, OPEN CELL 0.14 gm/cc	KAYLON	UNIROYAL INC.
309	9FR618B	SILICONE SPONGE 9.4 LB/FT^3		KIRKHILL RUBBER

CANDIDATE MATERIALS TESTED (CONT'D)

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
310	LS FORMULA T1218	NEOPRENE FOAM 7.5 PCF		TOYAD CORP.
311	3-6551/ 96081/KYNOL	SILICONE FOAM CEMENTED TO KYNOL FABRIC WITH 96-081 ADHESIVE 103 OZ/YD^2		DOW CORNING
312	TOSIL SILICONE	SILICONE FOAM FROM JAPAN (GE AFFILIATE) 18.9 LB/FT^3	TOSIL	GE
313	E-300	URETHANE FOAM, FLAME RETARDED 3.1 PCF	EMPIRE	CREST-FOAM CORP. MOONACHIE, NJ
314	T-47FR	URETHANE FOAM	TEMPER FOAM	EDMONT WILSON REP CMS ASSOCIATES, CMS INC. ENCINO, CA
315	200	POLYIMIDE FOAM NAS 9-15050		SOLAR TURBINES INTERNATIONAL SAN DIEGO, CA VIA NASA HOUSTON

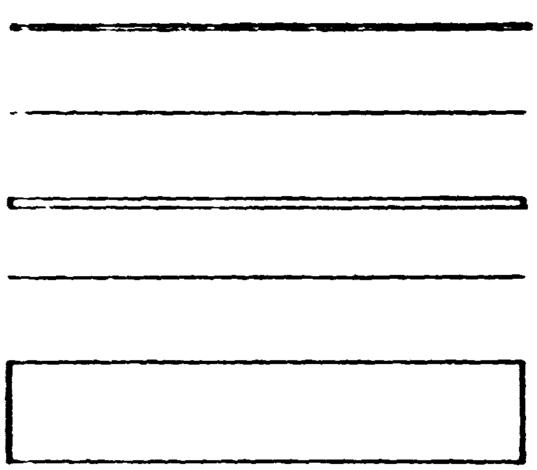
CANDIDATE MATERIALS TESTED (CONT'D)

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
400	170	SILICONE ADHESIVE	SYLGARD	DOW CORNING CORP.
401		CARPET MOD ACRYLIC	BRUNSWALL	BRUNSWALL CORP.
402		POLYPHENYLENESULPHONE PPS THERMOPLASTIC	RADEL	UNION CARBIDE
403	57-1825	ABS THERMOPLASTIC SHEET	ROYALITE	UNIROYAL
404	10052-72D	RIGID URETHANE FOAM	HYPOL	W. R. GRACE & CO.
405	685	ADHESIVE	KWIKSTIK	COLUMBIA CEMENT CO., INC. 159 ITANSE AVE. FREEPORT, NY 11520
406	R1275N/F	ADHESIVE		COLUMBIA CEMENT CO., INC. 159 ITANSE AVE. FREEPORT, NY 11520
407	2332 N/F	ADHESIVE (NEOPRENE)	CON-BOND	COLUMBIA CEMENT CO., INC. 159 ITANSE AVE. FREEPORT, NY 11520
408	EC 4715	ADHESIVE	CONTACT BOND	3 MC ADHESIVE, COATING & SEALERS DIVISION
409	RTV 133	ADHESIVE, SILICONE		GENERAL ELECTRIC WATERFORD, NY

MATERIALS DROPPED AS CANDIDATES

	MATERIAL	PROBLEM
(200,201,202)	KYNOL FABRICS	POOR WEAVE AND COLORFASTNESS COLOR AVAILABILITY
(102)	COTTON KNIT	COLORFASTNESS
(103)	NOMEX FABRIC	COLORFASTNESS
(106)	VONAR-BACKED NYLON	NO LONGER AVAILABLE
(107)	URETHANE-COATED NYLON	LOW STRENGTH (TEAR)
(204, 205)	PBI FABRICS	THERMAL SHRINKAGE
(206)	BLACK BATTING 40-4010-1	EXTREME TOXICITY
(207)	KYNOL NEEDLED TO REMAY	THERMAL WEIGHT LOSS
(212)	DURETTE UPHOLSTERY FABRIC	COLORFASTNESS
(215)	KERMEL FABRIC	THERMAL SHRINKAGE
(301)	R-207080 APN PHOSPHAZENE FOAM	LOW STRENGTH
(302)	HYPOL URETHANE FOAM	HIGH SMOKE GENERATION
(304)	14183-B SILICONE FOAM	HIGH HEAT RELEASE
(305)	510 SILICONE FOAM	FAILS BURN TEST
(308)	KOYLON NEOPRENE FOAM	FAILS SMOKE GENERATION

FUTURE SEAT COMPONENTS



DECORATIVE FABRIC COVER

SLIP SHEET (TOPPER)

FIRE BLOCKING LAYER

CUSHION REINFORCEMENT

CUSHIONING LAYER

NOTE: SOME COMPONENTS MAY NOT BE INCLUDED IN ALL DESIGNS

DECORATIVE FABRIC COVER

KEY REQUIREMENTS — *COLORFAST
COLOR AVAILABILITY
RESISTANCE TO IGNITION
LOW FLAME SPREAD
WEARABILITY
LOW TOXICITY
LOW SMOKE GENERATION

CANDIDATE MATERIALS —

(100)	ST-7793-29	AIRGARD-TREATED NYLON	C&A
(101)	20787	KERMEL 47 PERCENT WOOL 53 PERCENT BLEND LELIEVRE	

*GO-NO GO REQUIREMENT

SLIP SHEET

KEY REQUIREMENTS — LOW WEAR
LOW FRICTION
IGNITION RESISTANCE
LOW FLAME SPREAD
LOW TOXICITY
LOW THERMAL SHRINKAGE

CANDIDATE MATERIALS —

(214)	NOMEX III	ARAMID 254 g/m^2	DUPONT
(217)	400-6	DURETTE DUCK	FIRE SAFE PROD.

FIRE BLOCKING LAYER

KEY REQUIREMENTS — BURN RESISTANCE
LOW SMOKE GENERATION
LOW HEAT RELEASE
LOW FLAME SPREAD
LOW TOXICITY
LOW THERMAL CONDUCTIVITY
GOOD CHAR FORMATION

CANDIDATE MATERIALS

(203)	13-104	KYNOL NEEDLE PUNCH BATTING	AMER KYNOL INC.
(210)	VONAR NO. 3	NEOPRENE FOAM INTERLINER	DUPONT
(214)	NOMEX III	NOMEX FABRIC	DUPONT
(216)	400-11	DUREJTE BATTING	FIRE SAFE PROD.

CUSHIONING REINFORCEMENT

KEY REQUIREMENT — WEAR RESISTANCE
BURN RESISTANCE
COMPATIBILITY
(i.e., ADHESION STIFFNESS CEMENTABILITY)
LOW TOXICITY

CANDIDATE MATERIALS —

(213)	SE-559	SILICONE ELASTOMER.	GE
(214)	NOMEX III	FABRIC	DUPONT
(217)	400-6	DURETTE DUCK FABRIC	FIRE SAFE PROD.

CUSHIONING

KEY REQUIREMENTS — LOW TOTAL HEAT RELEASE
LOW TOXICITY
LOW SMOKE GENERATION
LOW FLASH PROPENSITY
(LOW WEIGHT LOSS)
● BREAKDOWN RESISTANCE

CANDIDATE MATERIALS —

(30/)	HL 1-7-77 NEOPRENE FOAM	TOYAD CORP.
(300)	FG 215 GLASS FIBER BLOCK	EXPANDED RUBBER
(303)	EXP 1408 SILICONE FOAM	KIRKHILL RUBBER
*	LS NEOPRENE FOAM	TOYAD CORP.
*	9 FR 618 SILICONE FOAM	KIRKHILL RUBBER

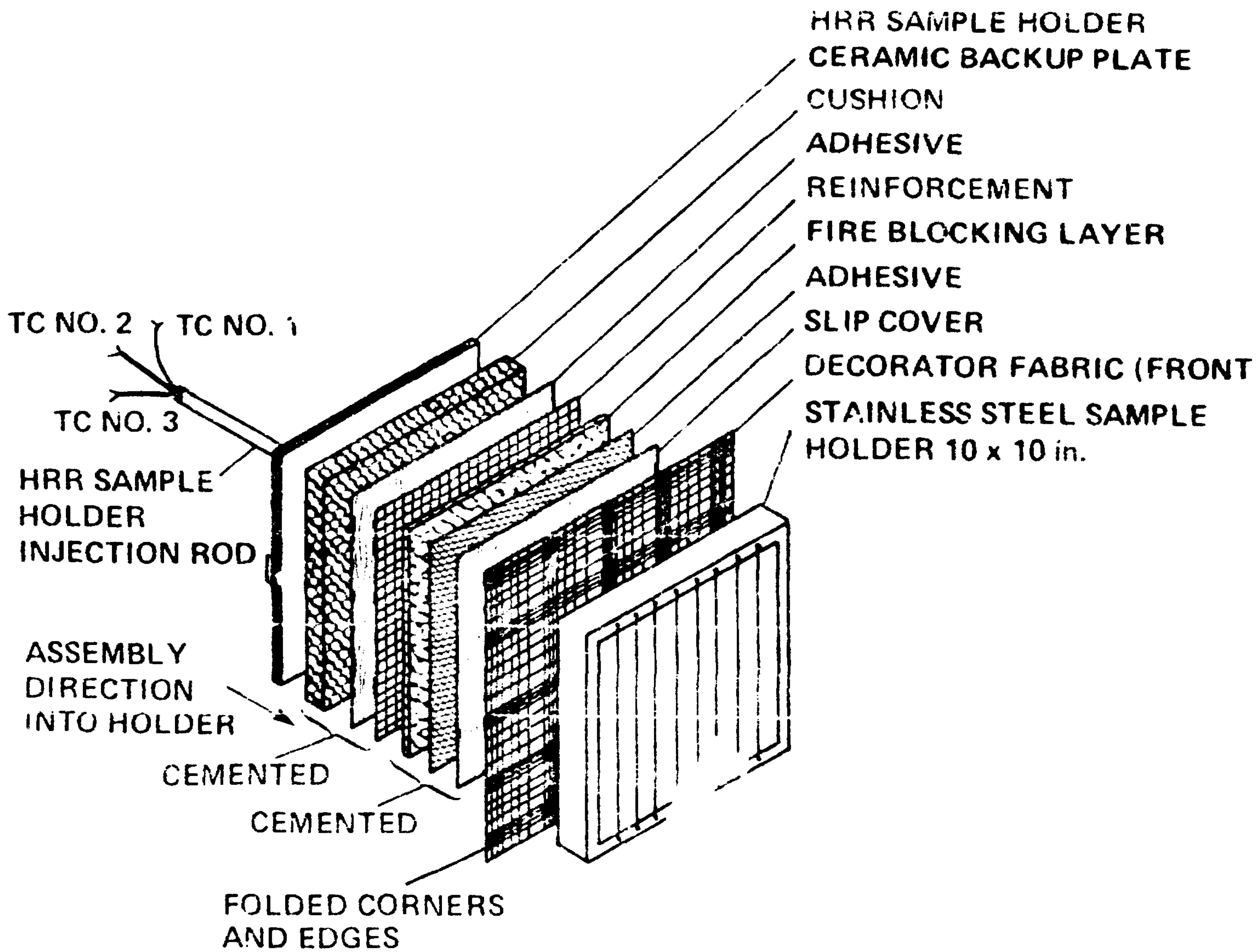
*NOT SCREENED TO DATE

HEAT RELEASE RATE TESTING

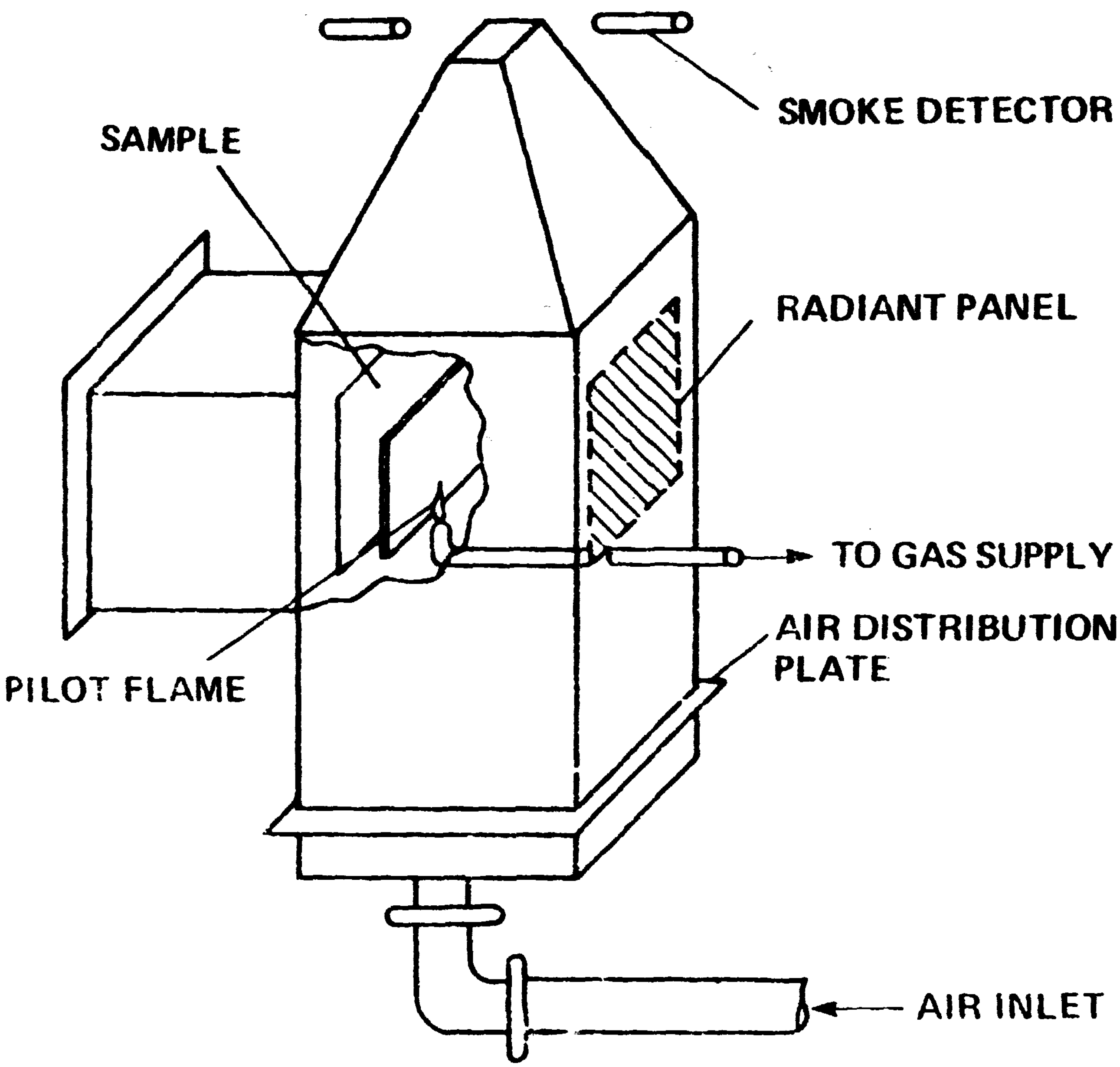
PART 1 STANDARD CUSHION LAYER OF GLASS BLOCKING WITH VARIOUS UPPER LAYERS

PART 2 SELECTED UPPER LAYERS FROM PART 1 WITH VARIOUS CUSHION LAYERS

TYPICAL MULTIPLE LAYER TEST SPECIMEN



OSU HEAT RELEASE APPARATUS



MATERIALS UTILIZED IN THE CONSTRUCTION OF MULTILAYER ASSEMBLIES

SAMPLE NO.	SAMPLE FORM	GENERIC NAME	MATERIAL DESCRIPTION	MATERIAL DENSITY	FUNCTION IN MULTILAYER ASSEMBLY
1	FABRIC	AMIDE-IMIDE WOOL	52.5% KERMEL/47% WOOL	290 g/m^2	DECORATIVE COVERING LAYER
2	FABRIC	WOOL/AMIDE	90% WOOL/10% NYLON	457 g/m^2	DECORATIVE COVERING LAYER
3	FABRIC	ARAMID	NOMEX III	254 g/m^2	SLIP COVER CUSHION REINFORCEMENT
4	BATTING	CHLORINATED ARAMID	DURETTE	–	FIRE BLOCKING LAYER
5	FOAM	POLYCHLORO-PRENE WITH COTTON SCRIM	0.475 cm THICK POLYCHLOROPRENE	954 g/m^3	FIRE BLOCKING LAYER
6	DUCK	CHLORINATED ARAMID	DURETTE	–	CUSHION REINFORCEMENT
7	FABRIC	NOVOLOID	KYNOL	213 g/m^2	FIRE BLOCKING LAYER

MATERIALS UTILIZED IN THE CONSTRUCTION OF MULTILAYER ASSEMBLIES (CONTINUED)

SAMPLE NO.	SAMPLE FORM	GENERIC NAME	MATERIAL DESCRIPTION	MATERIAL DENSITY	FUNCTION IN MULTILAYER ASSEMBLY
8	FABRIC		SILICONE ELASTOMER ON GLASS FABRIC	–	CUSHION REINFORCEMENT
9	ADHESIVE		R2332 NF	--	CEMENT
10	ADHESIVE		RTV 133	–	CEMENT
11	FOAM	URETHANE	POLYURETHANE FOAM	0.20 g/cm^3	CUSHION
12	FOAM	GLASS	GLASS FIBER BLOCK CUSHION	0.03 g/cm^3	CUSHION
13	FOAM	IMIDE	POLYIMIDE FOAM	0.06 g/cm^3	CUSHION
14	ELASTOMER	SILICONE	SILICONE RUBBER SPONGE	0.19 g/cm^3	CUSHION
15	FOAM	POLYCHLORO-PRENE	LOW SMOKE NEOPRENE FOAM	0.14 g/cm^3	CUSHION

MULTILAYER MATERIALS WITH GLASS FIBER BLOCK BACKING

ML SPECIMEN NO.	ADHESIVE	FIRE BLOCK	REINFORCEMENT	ADHESIVE
1	R2332NF	B1045 KYNOL	NOMEX III	SAME
2	R2332NF	B1045 KYNOL	DURETTE DUCK 400-6	SAME
3	R2332NF	B1045 KYNOL	SE5559 ON GLASS FABRIC	RTV 133
4	R2332NF	VONAR #3	SE5559 ON GLASS FABRIC	RTV 133
5	R2332NF	VONAR #3	NOMEX III	SAME
6	R2332NF	VONAR #3	DURETTE 400-6	SAME
7	R2332NF	DURETTE BATT 400-11	SE5559 ON GLASS FABRIC	RTV 133
8	R2332NF	DURETTE BATT 400-11	NOMEX III	SAME
9	R2332NF	DURETTE BATT 400-11	DURETTE DUCK 400-6	SAME

ALL ML SPECIMEN CONTAINED 52.5% KERMEL WOOL BLEND WITH NOMEX III SLIP COVER.

MULTILAYER MATERIALS WITH POLYMERIC FOAM BACKING

ML SPECIMEN NO.	ADHESIVE	FIRE BLOCK	REINFORCEMENT	ADHESIVE	CUSHION
10*	–	–	–	R2332NF	URETHANE FOAM H45C
11@	–	–	–	R2332NF	URETHANE FOAM H45C
12	R2332NF	DURETTE BATT 400-11	NOMEX III	SAME	POLYIMIDE FOAM
13	R2332NF	DURETTE BATT 400-11	NOMEX III	SAME	SILICONE FOAM
14	R2332NF	DURETTE BATT 400-11	NOMEX III	SAME	AL S-NEOPRENE FOAM
15	R2332NF	DURETTE BATT 400-11	NOMEX III	SAME	AL S-NEOPRENE FOAM CORED
16	R2332NF	DURETTE BATT 400-11	NOMEX III	SAME	ALS NEOPRENE FOAM
17α	–	VONAR #3	NOMEX III	R2332NF	POLYIMIDE FOAM
18α	–	VONAR #3	NOMEX III	R2332NF	SILICONE FOAM
19α	–	VONAR #3	NOMEX III	R2332NF	AL S-NEOPRENE FOAM
20°	–	–	–	R2332NF	URETHANE FOAM H45C
21	R2332NF	DURETTE BATT 400-11	PBI 40-9031-2	SAME	AL S-NEOPRENE FOAM

ML SPECIMENS CONTAINED 52.5% KERMEL/47.5% WOOL BLEND WITH NOMEX III SLIP COVER.

* ML SPECIMEN CONTAINED 90% WOOL/10% NYLON BLEND WITH FLAME RETARDED COTTON MUSLIN SLIP COVER.

@ ML SPECIMEN CONTAINED 52.5% KERMEL/47.5% WOOL BLEND WITH FLAME RETARDED COTTON MUSLIN SLIP COVER.

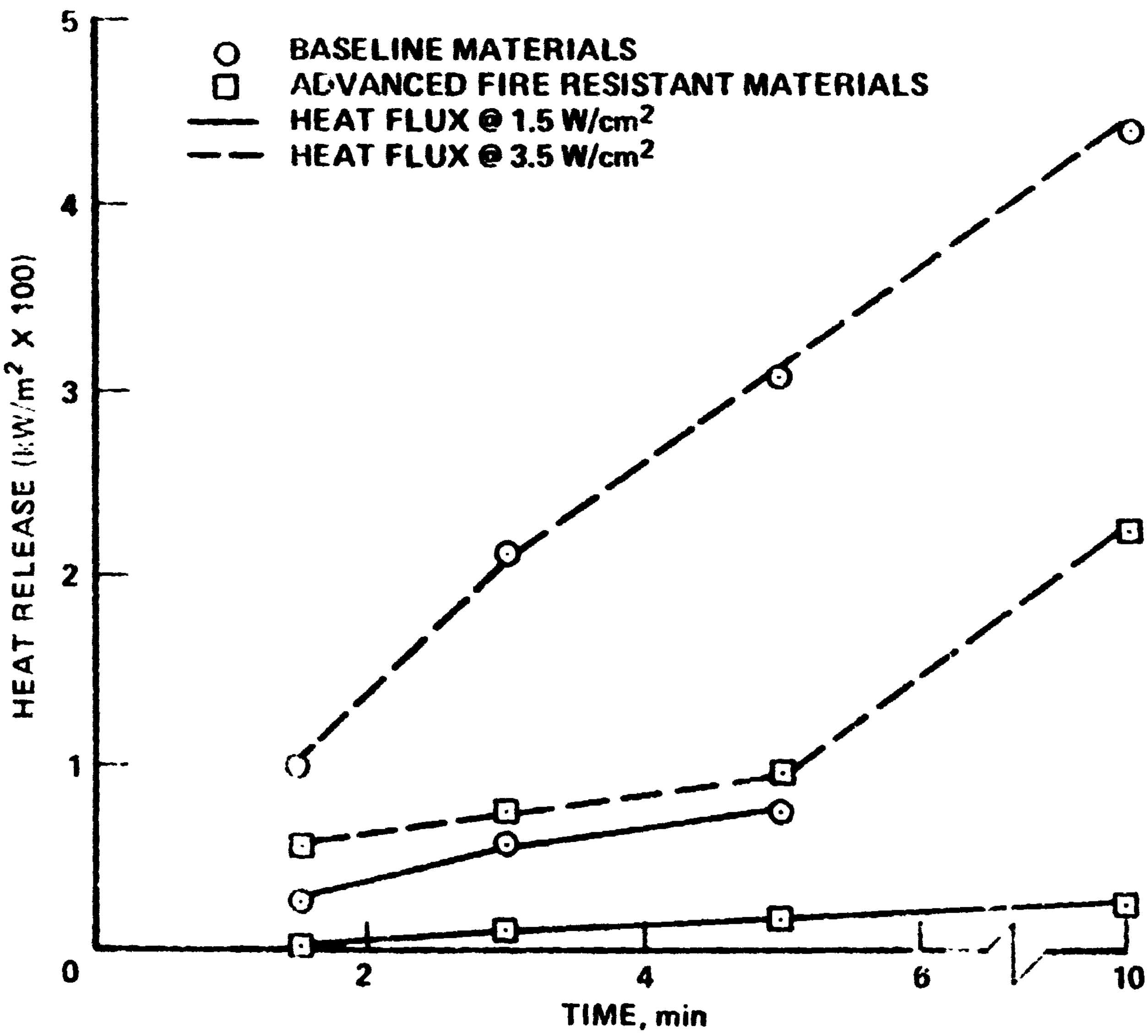
α ML SPECIMEN CONTAINED 52.5% KERMEL/47.5% WOOL BLEND WITH NO SLIP COVER.

° ML SPECIMEN CONTAINED FLAME RETARDED COTTON MUSLIN SLIP COVER.

THERMAL FLUX — HEAT RELEASE

TIME OF EXPOSURE	HEAT FLUX		HEAT FLUX	
	1.5	3.5	1.5	3.5
1.5 MIN	25.7	99	3.7	56.9
3 MIN	57.6	212	10.5	74.1
5 MIN	72.1	319	14.6	93.2
10 MIN	—	438	28.3	220
SPECIMEN NO.	20	10	21	16
DESCRIPTION OF LAYERS				
DECORATIVE	(104)	(104)	(101)	(101)
SLIP COVER	COTTON	COTTON	(214)	(214)
FIRE BLOCK	—	—	(216)	(216)
REINFORCEMENT	—	—	(222)	(214)
CUSHION	(306)	(306)	(310)	(310)

COMPARISON OF HEAT RELEASE FROM ADVANCED AND BASELINE MATERIALS



FIRE SOURCE DETERMINATION

AIRCRAFT SURVEY

AIRLINE TRASH DATA

AIRPLANE: DC-10 DATE: 2-23-78

	BAG 1	BAG 2	BAG 3	BAG 4	BAG 5	BAG 6
AIRCRAFT ORIGIN	CHICAGO	CHICAGO	CHICAGO	LONDON	LONDON	LONDON
SEAT NO./LOCATION	22K AND L/COACH	5K/FIRST CLASS	12D/COACH	UNKNOWN	12B/COACH	28F/COACH
LOCATION RELATIVE TO SEAT	ON FLOOR UNDER AND BEHIND SEAT	ON FLOOR BEHIND SEAT	ON FLOOR UNDER SEAT	UNKNOWN	IN POCKET ON BACK OF SEAT	ON FLOOR IN FRONT OF SEAT
ITEMS COLLECTED	NEWSPAPER – 7 SECTIONS AND ADS	HEADPHONE BAG USED CIGARETTE PACKS NEWSPAPER	2 NEWSPAPERS – ONE WITH SIX SECTIONS – ONE WITH FOUR SECTIONS	2 NEWSPAPERS	2 HEADSET BAGS 1 AIRSICK BAG 1 NAPKIN (COCKTAIL SIZE) 1 AIRLINE MAG	NEWSPAPER – 8 SECTIONS
WEIGHT OF ITEMS	1.44 POUNDS	1.50 POUNDS	2.15 POUNDS	1.52 POUNDS	0.45 POUNDS	1.25 POUNDS

AVERAGE WEIGHT OF ITEMS:
1.385 POUNDS

SUMMARY

- NEWSPAPER WAS THE MOST PREVALENT ITEM ON AIRCRAFT.
- THE MANNER IN WHICH NEWSPAPER WAS FOLDED AND PLACED WILL DETERMINE THE MAGNITUDE AND DURATION OF THE FIRE.
- THE NEWSPAPER IN THE FORM OF A TENT WILL GIVE A REPEATABLE FIRE.
- ONE AND ONE-HALF POUNDS OF NEWSPAPER WILL PROVIDE A MORE SEVERE FIRE THAN 3 POUNDS.

E. BARA

A REVIEW OF BOEING INTERIOR MATERIALS AND FIRE TEST METHODS DEVELOPMENT PROGRAMS

167

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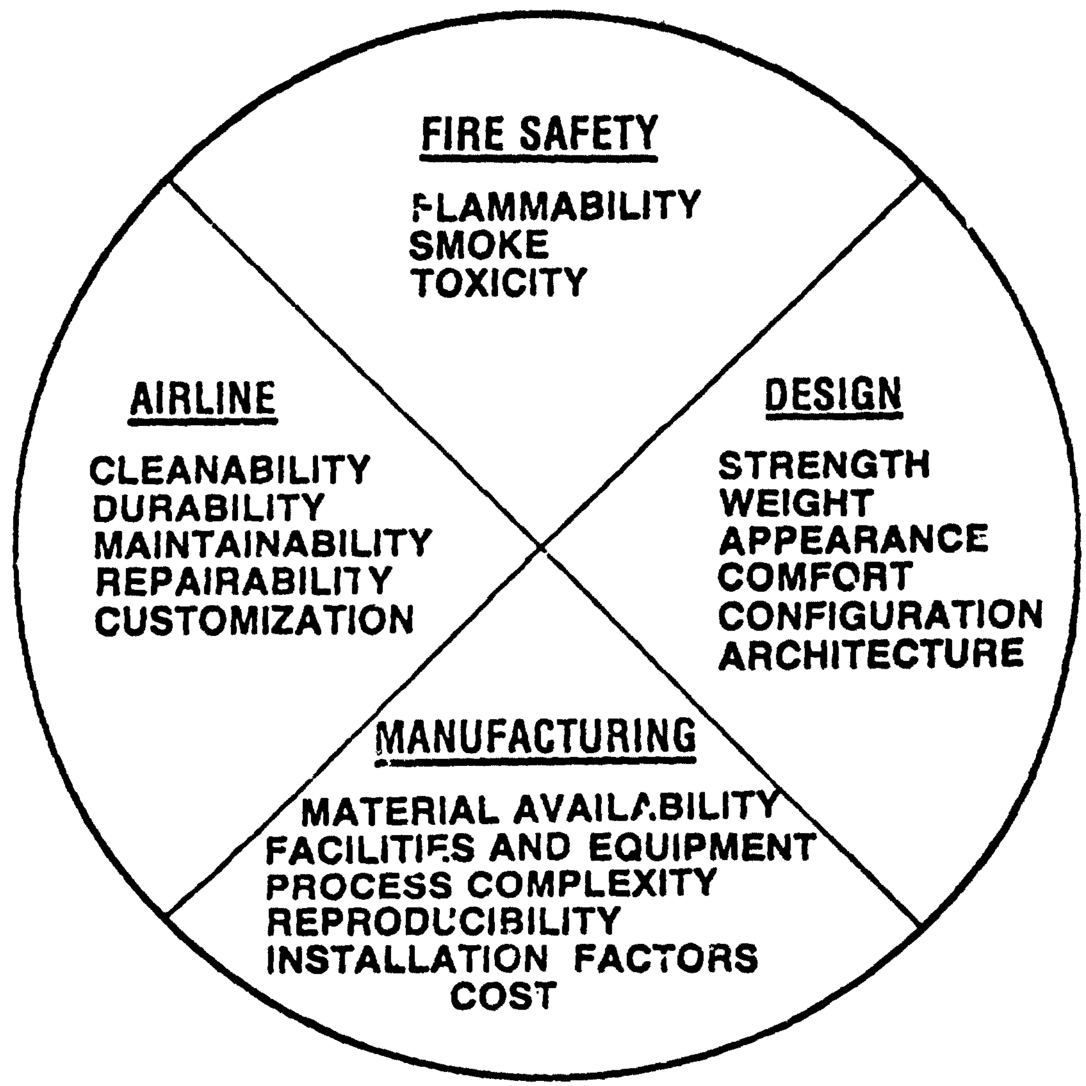
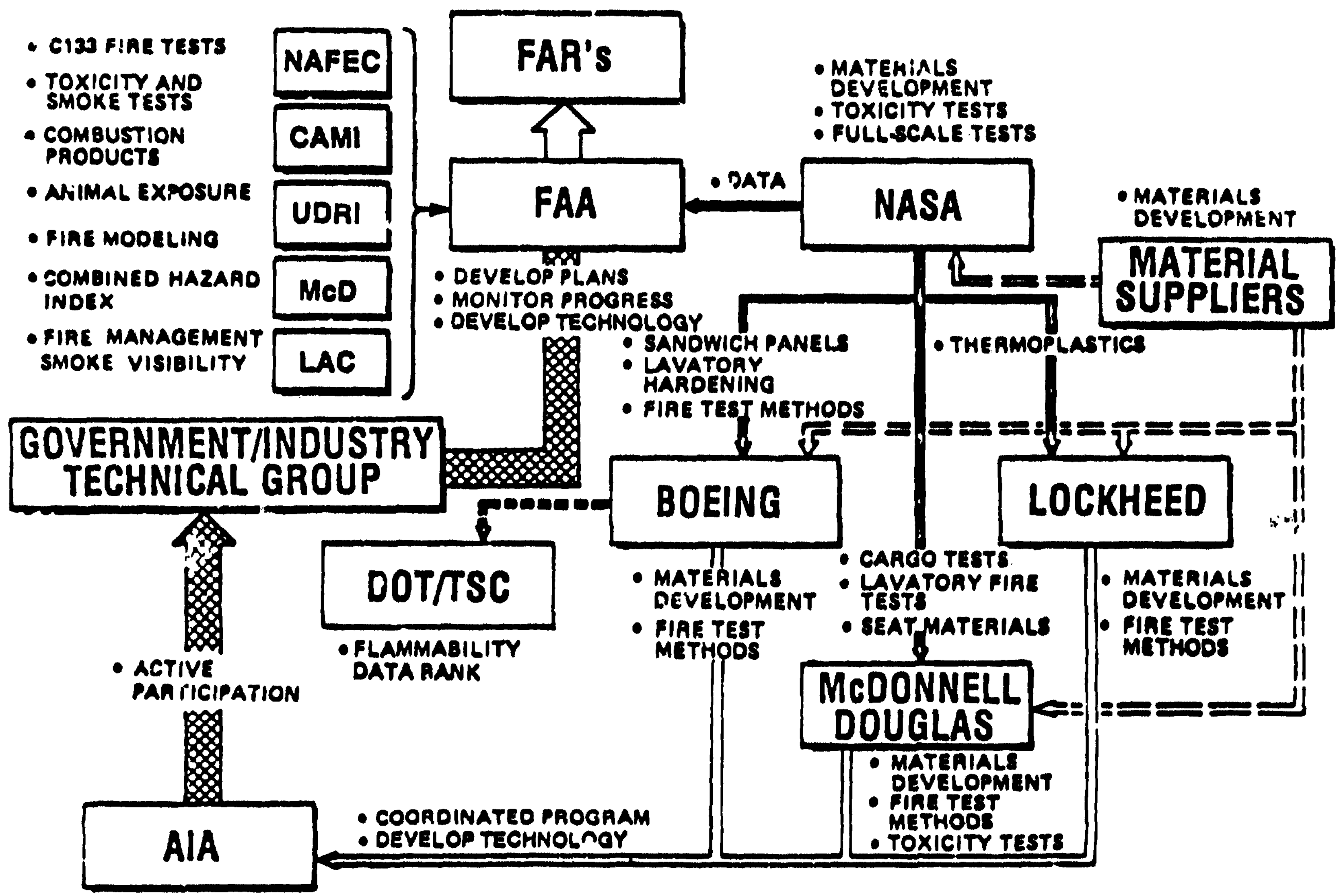
FEBRUARY 1979

TOTAL MATERIALS SYSTEMS REQUIREMENTS

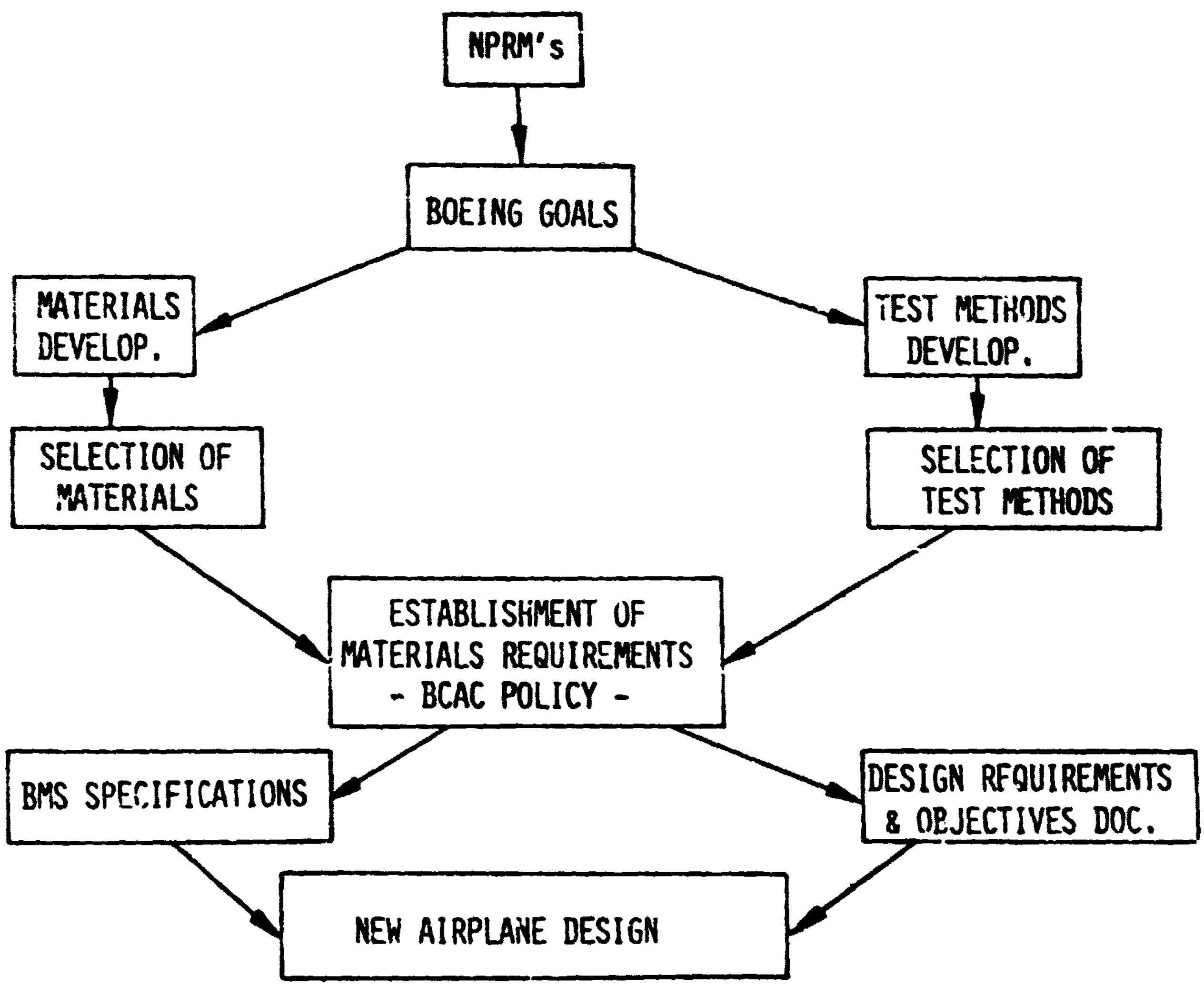


GOVERNMENT AND INDUSTRY PROGRAMS

PRESENTED AT FAA HEARING NOVEMBER 1977



INTERIOR MATERIALS DEVELOPMENT



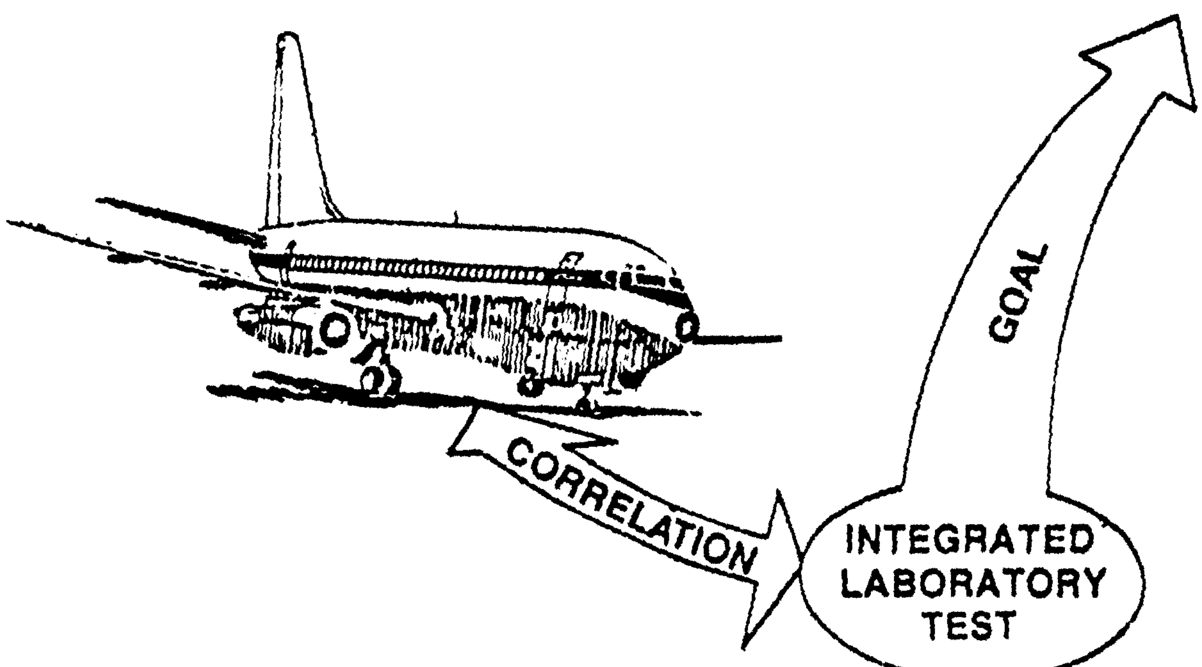
A NEW TEST METHODOLOGY CONCEPT

CABIN ENVIRONMENT TOLERANCE LIMITS

- TEMPERATURE
- VISIBILITY
- TOXIC GAS CONCENTRATION
- OTHERS

FUTURE MATERIALS

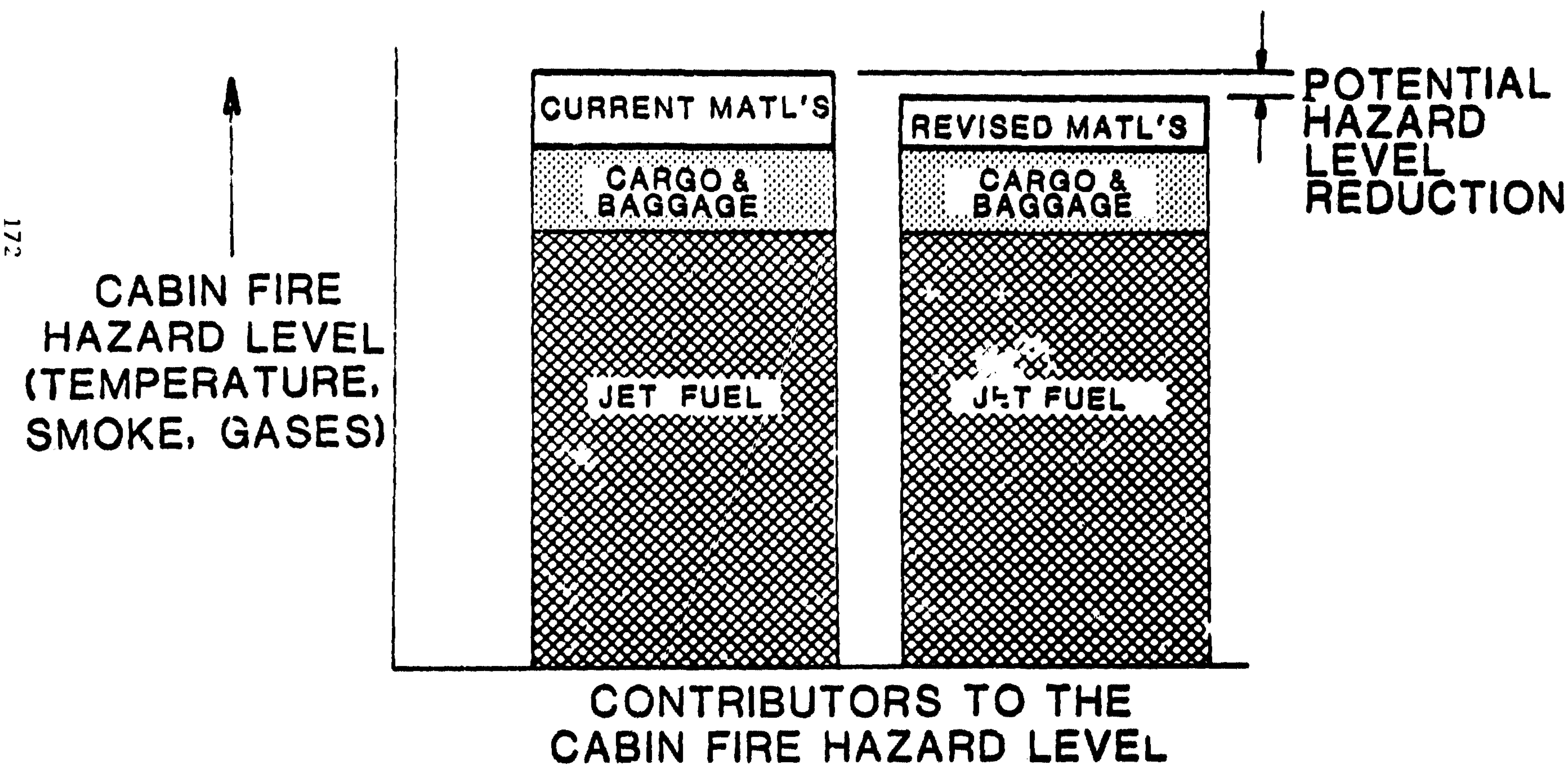
SELECTION BASED ON PREDICTED MATERIAL PERFORMANCE IN CABIN FIRE ENVIRONMENT



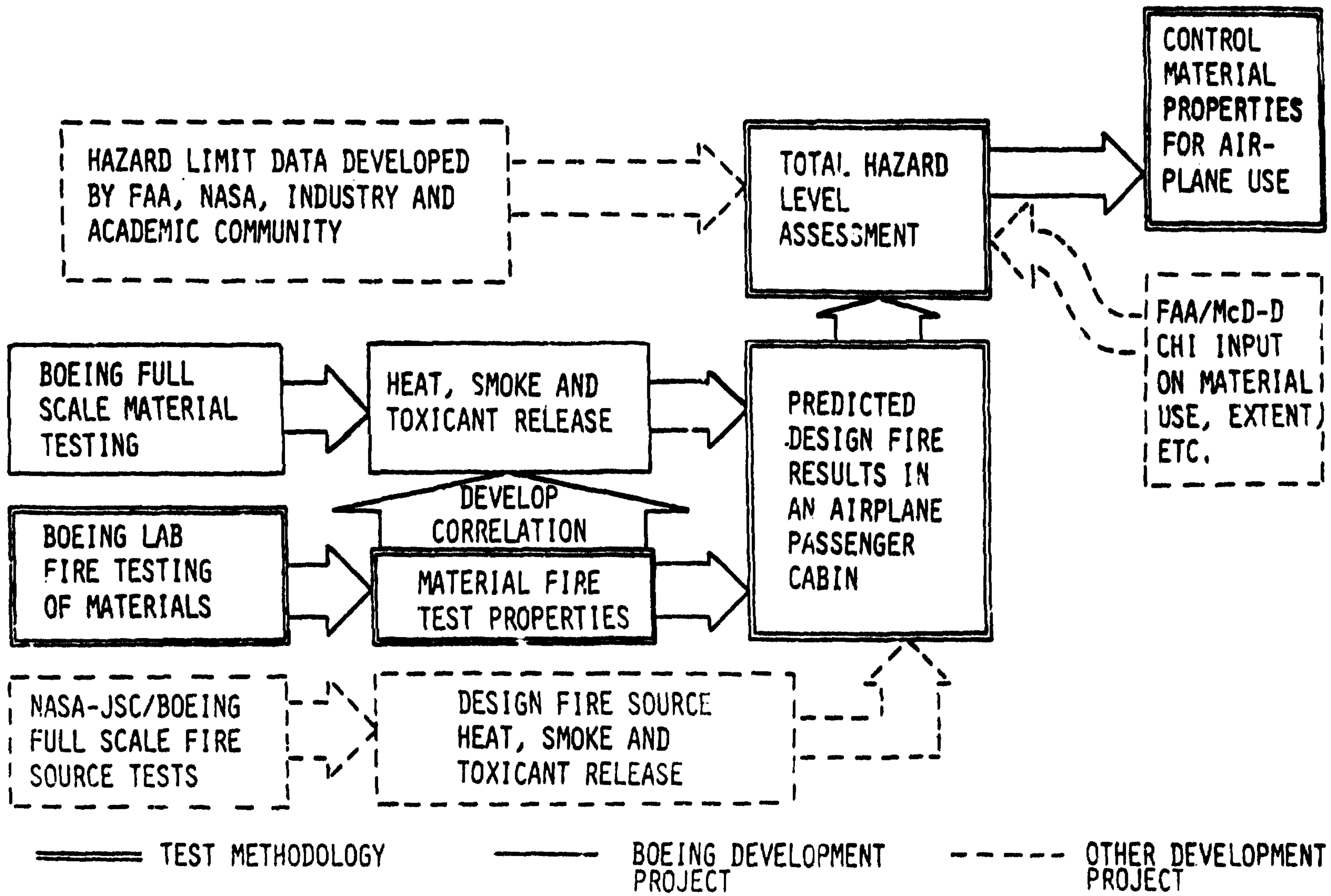
MATERIALS' PROPERTIES

- HEAT RELEASE
- SMOKE RELEASE
- TOXIC GAS EMISSION
- FLAMMABILITY
- OTHERS

POTENTIAL DECREASE IN FIRE HAZARD LEVEL
-POST CRASH FIRE-



BOEING FIRE TEST METHODOLOGY DEVELOPMENT



FIRE TEST METHODOLOGY PROGRESS

- ESTABLISHED DESIGN FIRE SOURCES (NASA CONTRACT NAS9-15168)

- SELECTED OSU APPARATUS AS POSSIBLE TEST METHOD FOR PREDICTION OF HEAT AND SMOKE IN AN AIRPLANE FIRE (REQUIRES FURTHER REFINEMENT)

- NEED MAJOR EFFORTS IN TOXICANT MEASUREMENT AND TOXICITY LIMITS

FLAMMABILITY, SMOKE AND TOXICITY GOALS

FLAMMABILITY

- FAR 25.583 AMMENDMENT 25-32
- FLAME SPREAD INDEX MAXIMUM 25
  - APPARATUS-ASTM E 162

SMOKE

NBS CHAMBER, 2.5 WATTS CM^2 HEAT FLUX:

4.0 MINUTES

- LARGE AREA, D_S MAXIMUM 50
- SMALL AREA, D_S MAXIMUM 200

TOXICITY

NBS SMOKE CHAMBER

GAS EMISSION (PPM)	CO	HCN	HF	HCl	SO_2	NO_2
TIME						
1.5 MINUTES	3000	100	150	50	30	50
4.0 MINUTES	3500	150	150	500	100	100

SCOPE - MAJOR MATERIALS SYSTEMS

DECORATIVE SANDWICH PANELS

COMPRESSION MOLDED FG.

THERMOPLASTICS

TRANSPARENCIES

INSULATION AND COVERINGS

SANDWICH AIR DUCTS

UPHOLSTERY FABRICS

FLEXIBLE DUCTS AND TUBING

FIBERGLASS LAMINATES

FLEXIBLE FOAMS

CARPETS AND UNDERLAYS

RIGID FOAMS

CARGO LINING

SCOPE - SECONDARY MATERIALS SYSTEMS

HIGH PRESSURE LAMINATES

COATED FABRICS

DRAPERY FABRICS

FLOOR COVERINGS

ELASTOMERS

SEALANTS AND ADHESIVES

ADVANCED COMPOSITES

FLOOR PANELS

POTTING COMPOUNDS

METAL LAMINATES

NEW MATERIAL/CURRENT MATERIAL COMPARISONS (EXAMPLES)

	SMOKE RELEASE			FLAME SPREAD & HEAT RELEASE				TOXICITY
	NBS D_s ①	OSU D_s ②	F.S. * 10^{-2} lb ③	ASTM E-162 Q	ASTM E-162 I_s ④	OSU J/CM^2 ⑤	F.S. * 10^6 J ⑥	NBS GOAL ⑦
FLEXIBLE DUCTING								
CURRENT	35.9	37	-	1.5	43	250	-	PASS
NEW	9.3	17	-	1.65	5	91	-	PASS
COMPRESSION MOLDED F.G.								
CURRENT	235-295	143-254	9.4	4-6	11-15	605-1404	2.0	PASS
NEW	8-109	6-58	5.8	2-5	3-15	476-767	1.2	PASS
THERMOPLASTICS								
CURRENT	130	462	18.3	5	24	1986	4.9	PASS
NEW	1-11	56-136	3.0	1.6-6.6	1.6-24	754-874	1.1	PASS
F.G. LAMINATES								
CURRENT	46.0	49.4	-	1.6	1.6	171	-	PASS
NEW	0.2	0.2	-	1.3	1.3	125	-	PASS
SIDEWALLS								
CURRENT (LAMINATED/ SANDWICH PANELS)	70-90	82-90	17-25	2 -3	23-50	471-698	1.8-2.0	PASS
NEW (SANDWICH PANELS)	49	47	PLANNED	1.6	7.2	344	PLANNED	PASS

① GOAL ≤ 50 @ 2.5 W/CM^2 @ 4 MIN. ② 5 W/CM^2 @ 90 SEC. ③ POST-CRASH @ 90 SEC.

④ GOAL ≤ 25 ⑤ 5 W/CM^2 @ 215 SEC. ⑥ POST-CRASH @ 215 SEC. ⑦ @ 2.5 W/CM^2 @ 4 MIN.

* SIMULATED FULL SCALE TEST DATA

PROGRESS IN MATERIALS DEVELOPMENT

- DEVELOPMENT OF MATERIALS TO GOALS IS NEARLY COMPLETE
- MAJOR LINING MATERIALS EVALUATED TO DATE FOR NEW AIRPLANE USE SHOW FIRE PROPERTY IMPROVEMENTS IN FULL SCALE AND LABORATORY TESTS
- THE REDUCTION IN AIRPLANE FIRE HAZARD IF NEW MATERIALS ARE USED IS NOT DEFINED

GOVERNMENTAL REGULATIONS

- RATIONAL BASIS NOT YET ESTABLISHED FOR ADDITIONAL REGULATION

    - CORRELATION OF LAB TEST TO AIRPLANE FIRE RESULTS APPEARS POSSIBLE- BUT METHODOLOGY YEARS AWAY

    - REDUCTION IN MATERIAL CONTRIBUTION TO AIRPLANE FIRE HAZARD CAN NOT BE APPRAISED YET

SAFER COMMITTEE SHOULD BE MADE OPERATIVE

- CCORDINATION ON NATIONAL LEVEL NEEDED FOR REASEARCH AND REGULATIONS

- SAFER STEERING GROUP MEMBERS MUST BE TECHNICALLY KNOWLEDGEABLE AND CAPABLE OF COMMITTING RESEARCH

D/2

N79-31178

FIREMEN PROGRAM

STATUS REPORT

R.A. Anderson and G.A. Johnson
Boeing Commercial Airplane Company
March 1979

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C-3

DEVELOPMENT AND FABRICATION PROGRAMS

DEVELOPMENT PROGRAM

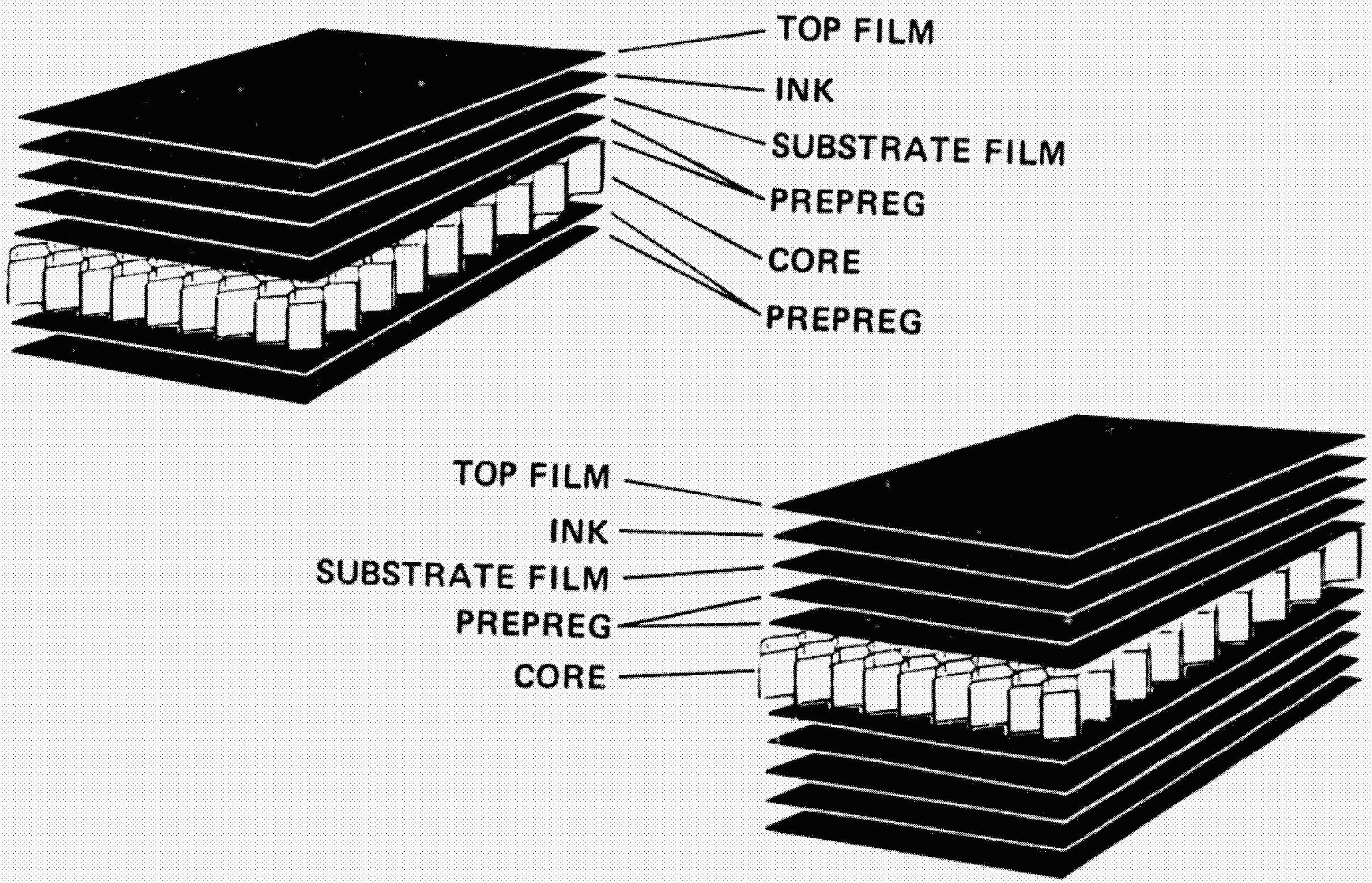
OVERVIEW

- BEGAN IN 1975
- FOUR PHASE PARTICIPATION
- INTERIOR SANDWICH PANEL DEVELOPMENT

OBJECTIVES

- IMPROVE
  - FLAMMABILITY
  - SMOKE EMISSION
  - TOXICITY
- MAINTAIN
  - MECHANICAL PROPERTIES
  - AESTHETICS
  - SERVICEABILITY
  - COSTS

SANDWICH PANEL MAKEUP



- PHASE I – BASELINE LAVATORY BURN
  (NAS2 – 8700)
- PHASE II – RESIN SYSTEM DEVELOPMENT
  (NAS2 – 8700)
- PHASE III – DECORATIVE FILM DEVELOPMENT
  (NAS2 – 8700)
- PHASE IV – DECORATIVE INK DEVELOPMENT
  (NAS2 – 9864)

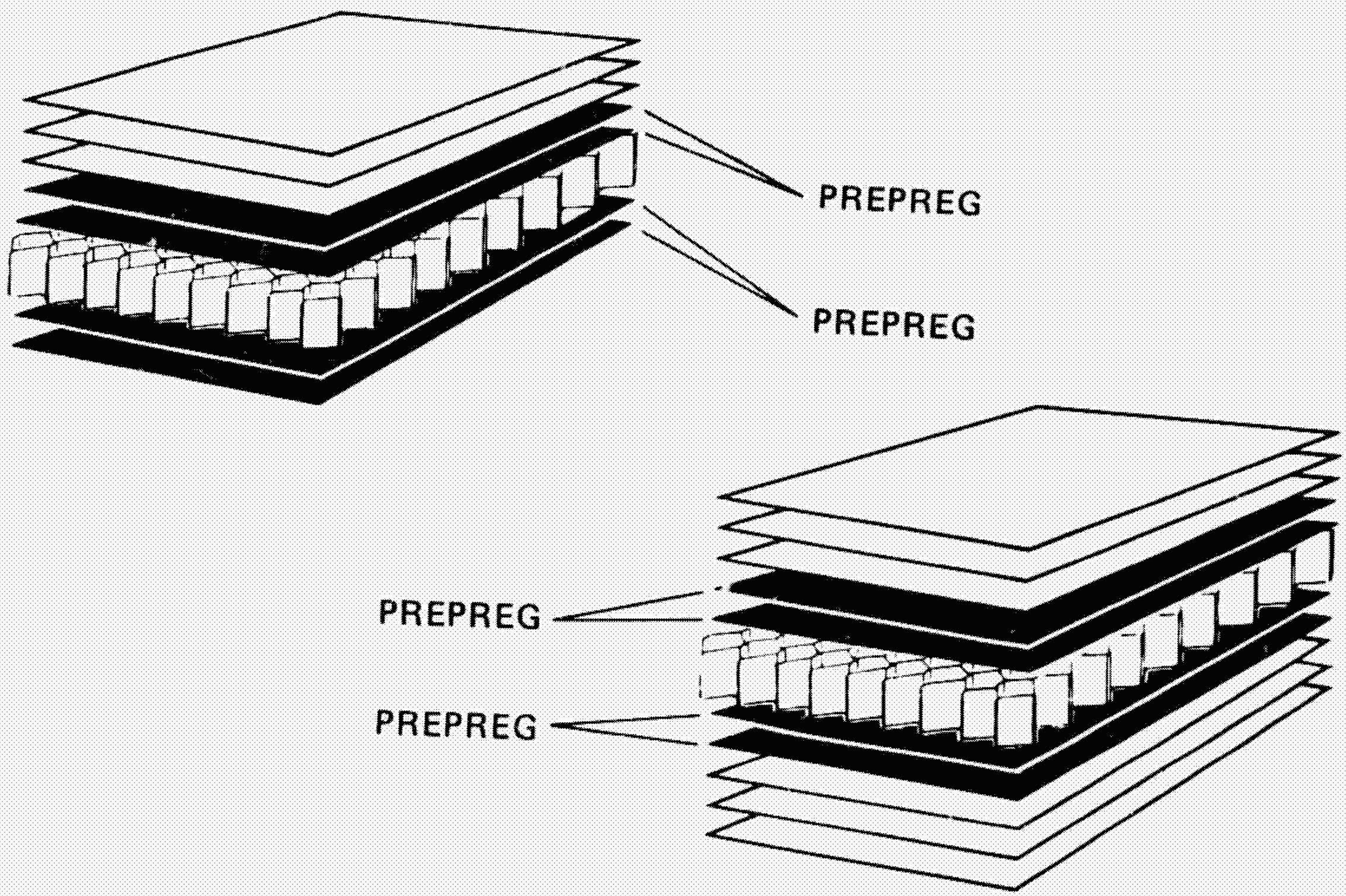
PHASE I – BASELINE LAVATORY BURN

- 747 LAVATORY MODULE
- TEST CONDITIONS
  - 30 MINUTES
  - DOOR CLOSED
  - 10 POUNDS TRASH
- INFLIGHT, UNOBSERVED FIRE

RESULTS

- FIRE CONTAINED
- CURRENT CONSTRUCTION ADEQUATE
- NASA CR-152074

PHASE II – RESIN SYSTEM DEVELOPMENT



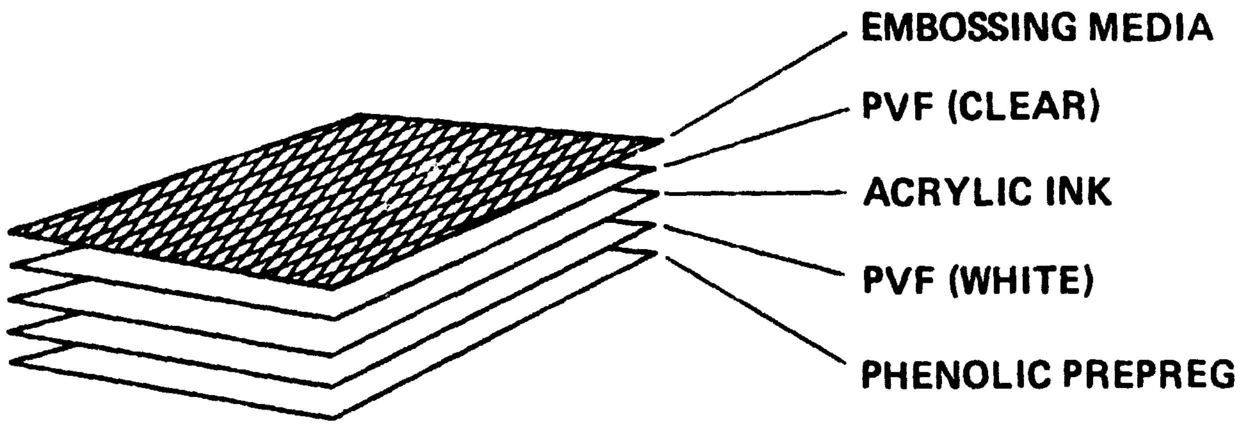
APPROACH

- CANDIDATE RESIN SYSTEMS
  - BASELINE EPOXY
  - BISMALEIMIDE
  - PHENOLIC
  - POLYIMIDE
- TESTING MATRIX
  - FLAMMABILITY, SMOKE, AND TOXICITY
  - MECHANICALS AND AESTHETICS

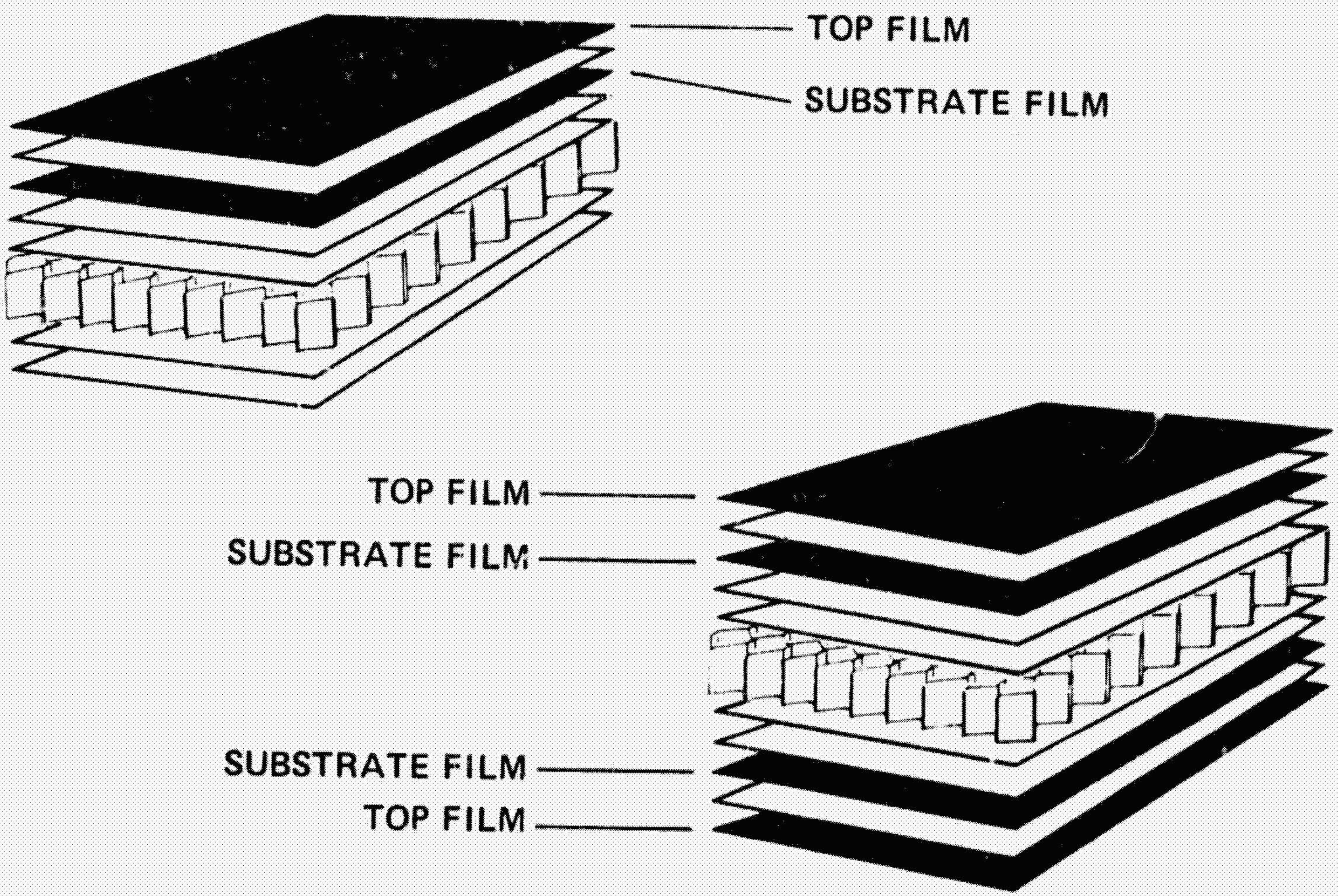
RESULTS

- PHENOLICS
  - FLAMMABILITY, SMOKE, AND TOXICITY
  - MATERIAL AND FABRICATION COSTS
  - LABORATORY SCALE TESTING
- PROBLEM
  - AESTHETICS
- NASA CR-152120

DECORATIVE LAMINATE MAKEUP



PHASE III – DECORATIVE FILM DEVELOPMENT



OVERVIEW

- NUMEROUS CANDIDATES
- TESTING MATRIX
  - FLAMMABILITY, SMOKE, AND TOXICITY
  - MECHANICALS AND AESTHETICS

APPROACH

- SINGLE FILM
- SOFT DECORATIVE LAMINATE
- HARD DECORATIVE LAMINATE
- SANDWICH PANEL

SINGLE FILM EVALUATION

- LOI
- D_S AT 1.5 AND 4 MINUTES
- D_M
- CO, HF, AND HCL AT 4 MINUTES
- 18 CANDIDATES

EVALUATION FORMULAS

$$A = \left(\frac{LOI}{300}\right) + \left(\frac{50 - D_S(1.5)}{450} + \frac{100 - D_S(4.0)}{900} + \frac{200 - D_M}{1800}\right)$$

$$+ \left(\frac{100 - CO}{900} + \frac{10 - HCL}{90} + \frac{100 - HF}{900}\right)$$

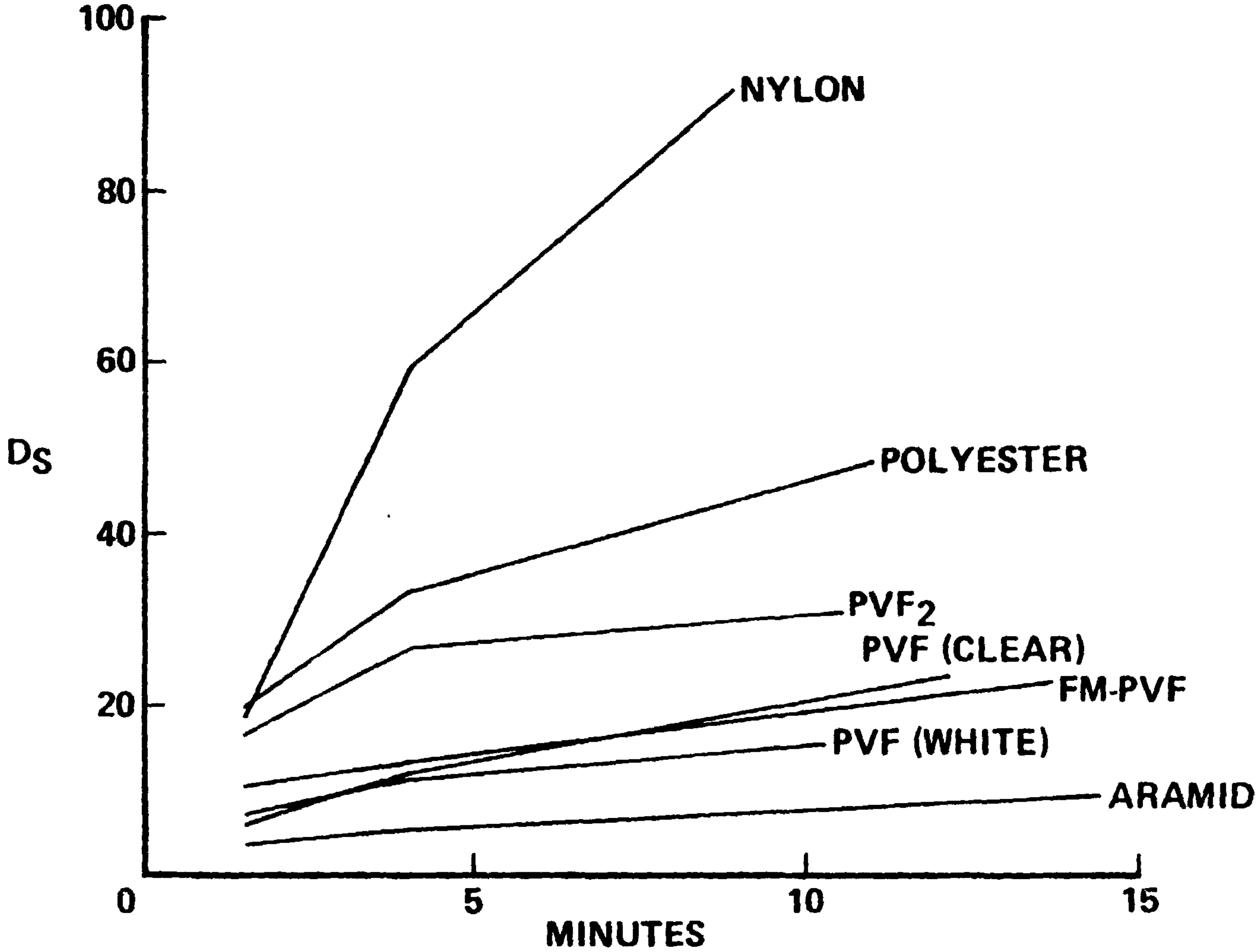
$$B = \left(\frac{LOI}{100}\right)^{1/3} \times \left[\left(\frac{50 - D_S(1.5)}{50}\right)\left(\frac{100 - D_S(4.0)}{100}\right)\left(\frac{200 - D_M}{200}\right)\right]^{1/9}$$

$$\times \left[\left(\frac{100 - CO}{100}\right)\left(\frac{10 - HCL}{10}\right)\left(\frac{100 - HF}{100}\right)\right]^{1/9}$$

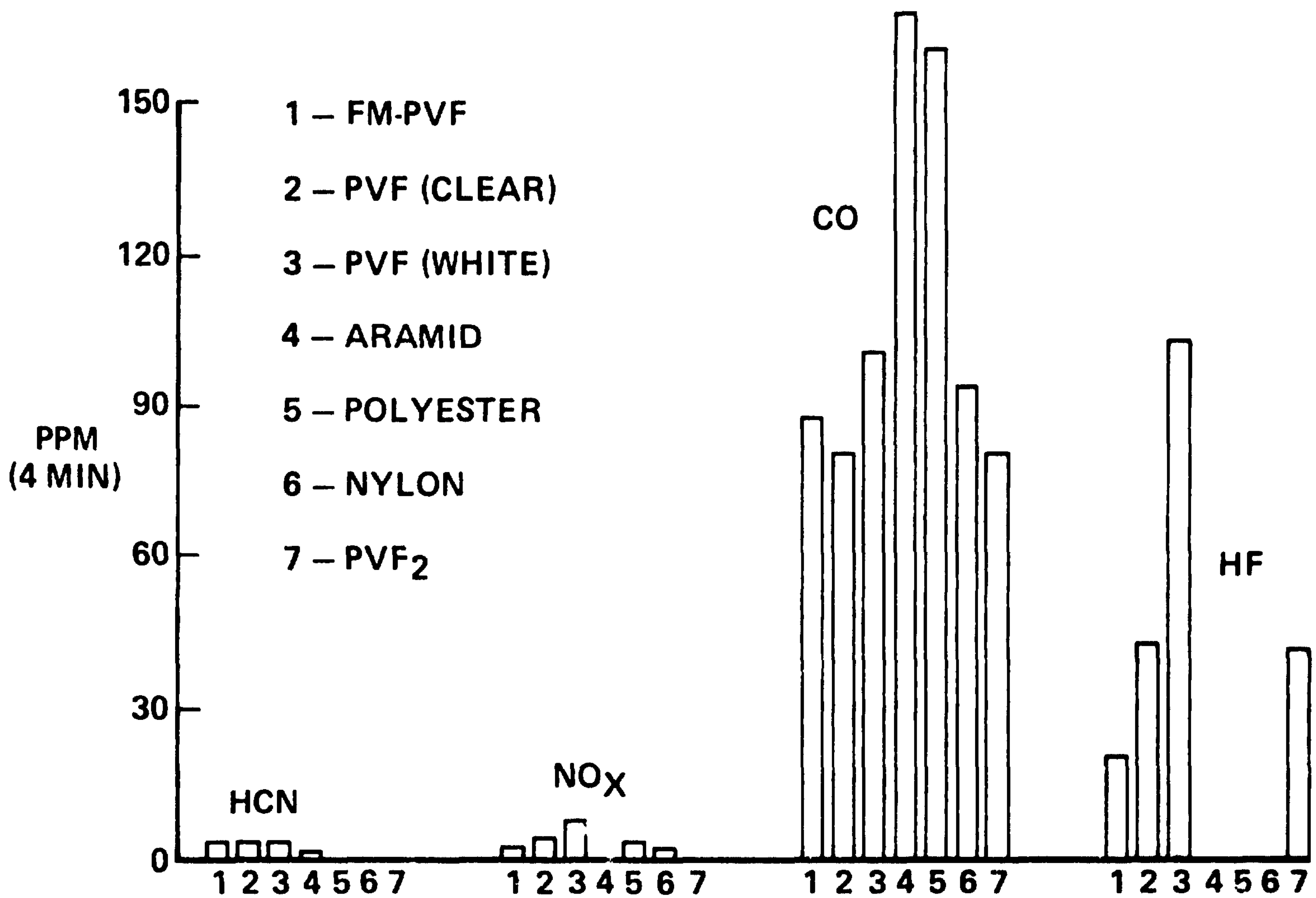
FURTHER EVALUATION

- PRINTABILITY
- EMBOSSABILITY
- UV STABILITY
- HEAT RELEASE
- SMOKE EMISSION
- TOXIC GAS EMISSION
- FLAME SPREAD INDEX
- 5 CANDIDATES

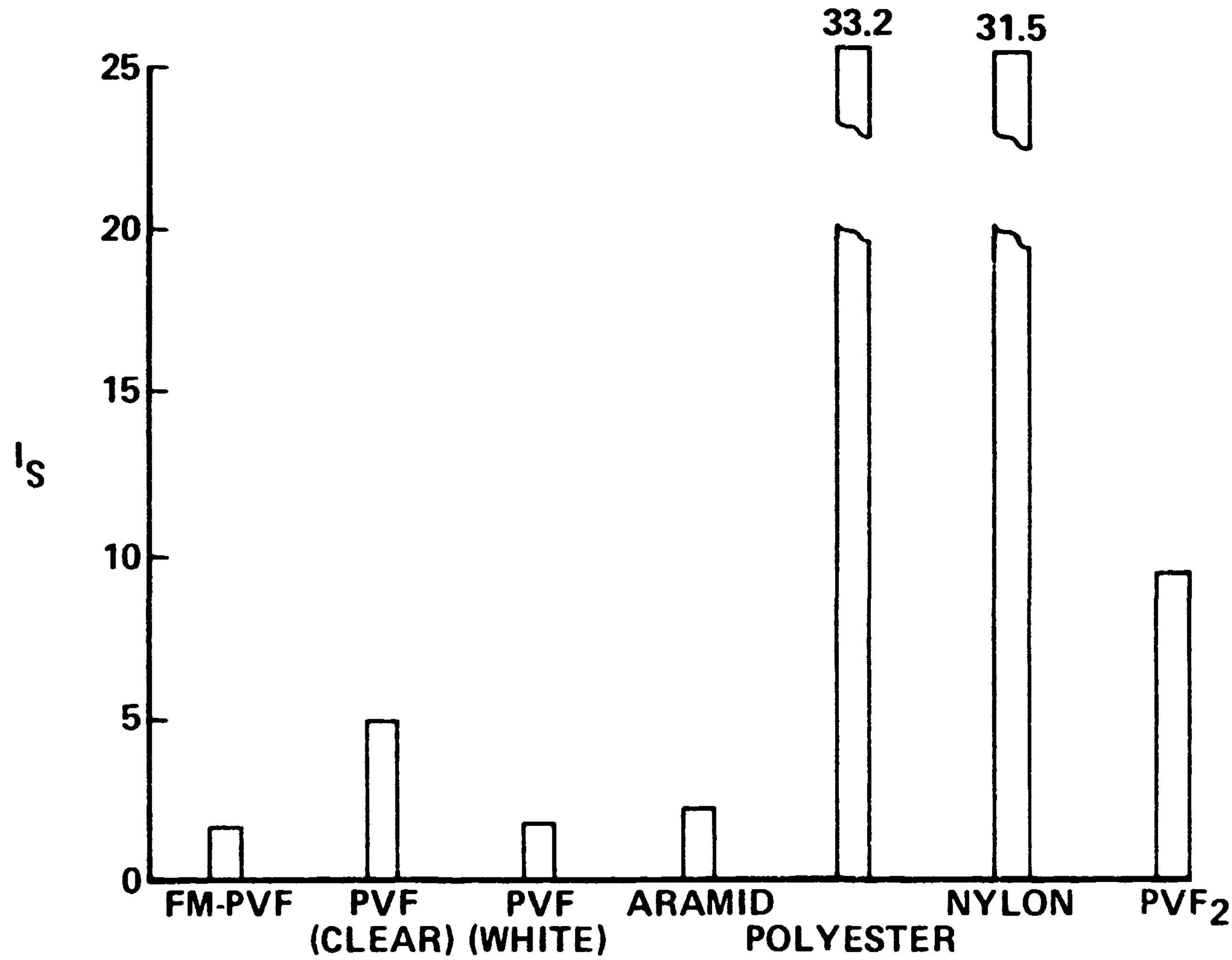
SMOKE EMISSION



TOXIC GAS EMISSION



FLAME SPREAD INDEX



EVALUATION FORMULAS

$$A = \left(\frac{35 - I_S}{105}\right) + \left(\frac{50 - D_S(1.5)}{450} + \frac{100 - D_S(4.0)}{900} + \frac{100 - D_M}{900}\right)$$

$$+ \left(\frac{200 - CO}{2400} + \frac{10 - HCN}{120} + \frac{10 - NO_X}{120} + \frac{150 - HF}{1800}\right)$$

$$B = \left(\frac{35 - I_S}{35}\right)^{1/3} \times \left[\left(\frac{50 - D_S(1.5)}{50}\right)\left(\frac{100 - D_S(4.0)}{100}\right)\left(\frac{100 - D_M}{100}\right)\right]^{1/9}$$

$$\times \left[\left(\frac{200 - CO}{200}\right)\left(\frac{10 - HCN}{10}\right)\left(\frac{10 - NO_X}{10}\right)\left(\frac{150 - HF}{150}\right)\right]^{1/12}$$

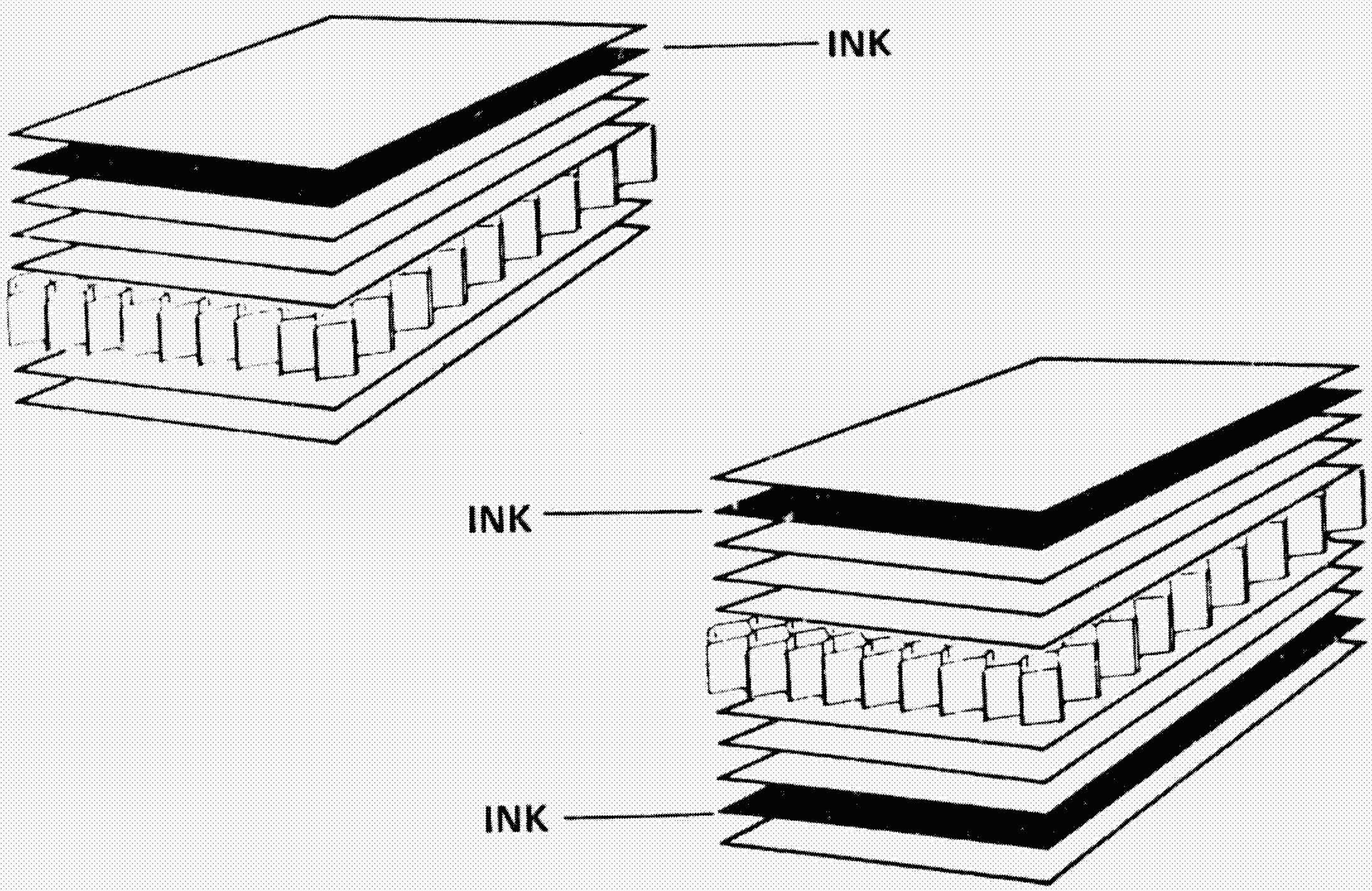
CURRENT CANDIDATES

- TOP FILM
  - PVF (CLEAR)
- SUBSTRATE FILMS
  - ARAMID
  - FM-PVF
  - PVF (WHITE)
  - PVF_2
  - DUPONT EXPERIMENTAL
  - FPE-P

FUTURE WORK

- SOFT DECORATIVE LAMINATES
  - SMOKE AND TOXIC GAS EMISSION
  - 60 SEC VERTICAL FLAMMABILITY
  - PEEL STRENGTH
- HARD DECORATIVE LAMINATES
  - PEEL STRENGTH
  - AESTHETICS
  - ABRASION RESISTANCE

PHASE IV – DECORATIVE INK DEVELOPMENT



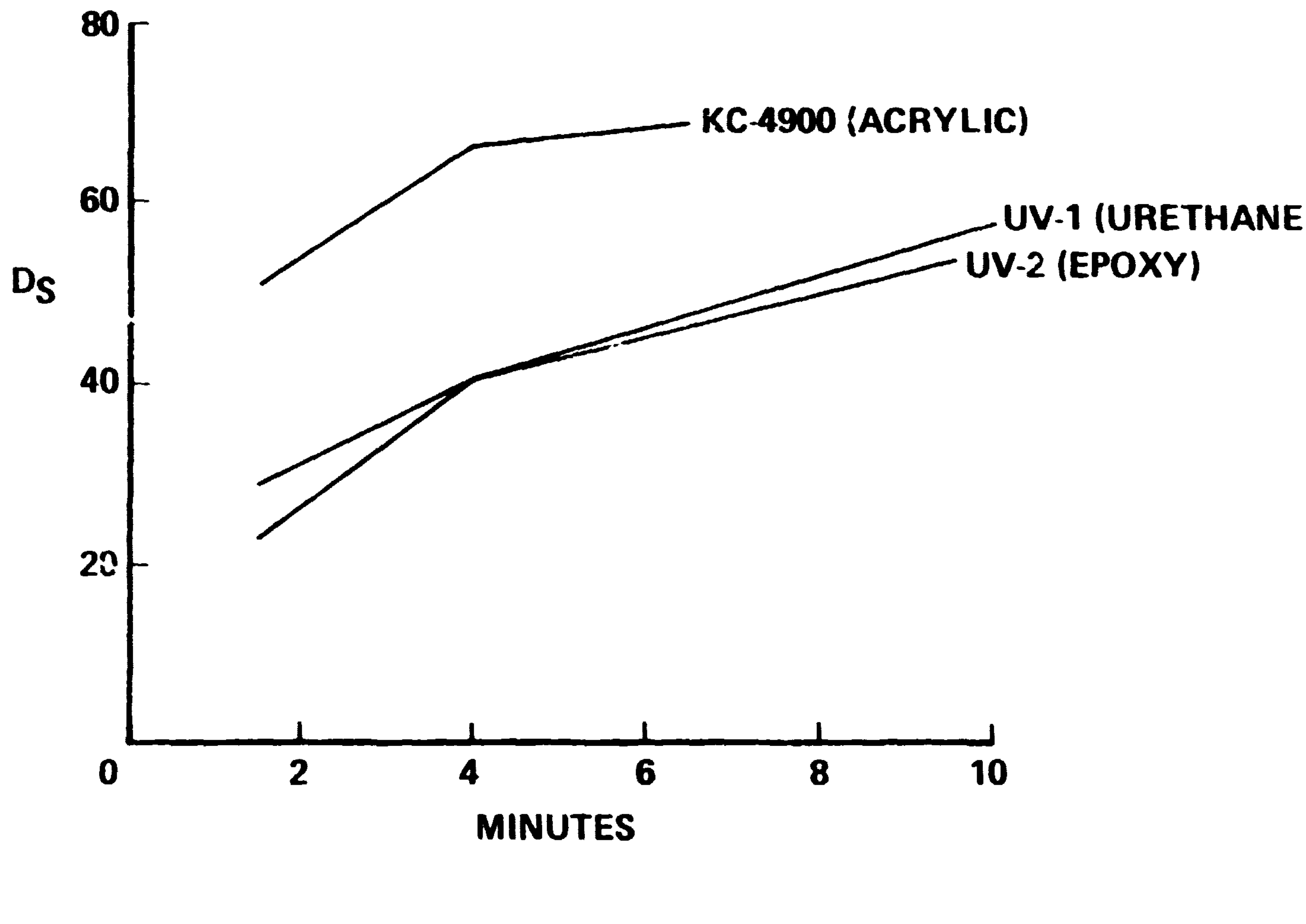
MATERIAL REQUIREMENTS

- 5 MIL FILM
- LOI $\geqslant$ 35
- $D_S \leqslant 20$ (2.5 W/CM^2, 4 MINUTES)
- TGA (N_2 AND AIR) RT $\rightarrow$ 250° C
- $LC_{50} \geqslant 70$ MG/L

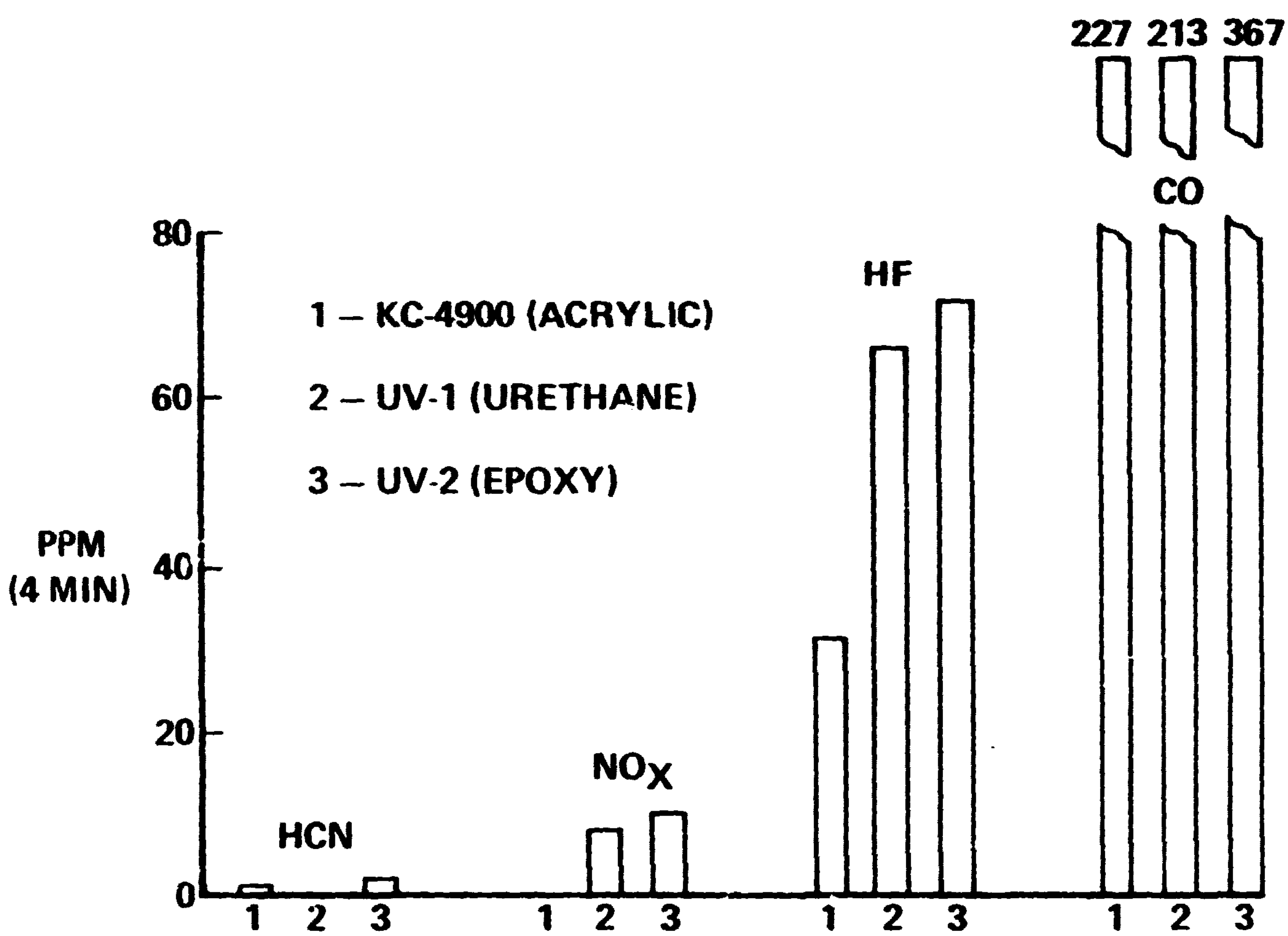
APPROACH

- UV CURED INKS
  - VISCOSITY VARIATION
  - AIR QUALITY REGULATIONS
  - TECHNOLOGY AVAILABLE
- SUBCONTRACT
  - K.C. COATINGS, INC.
  - 6-MONTH EFFORT
  - NEGOTIATIONS IN PROGRESS

SMOKE EMISSION



TOXIC GAS EMISSION



FABRICATION PROGRAMS

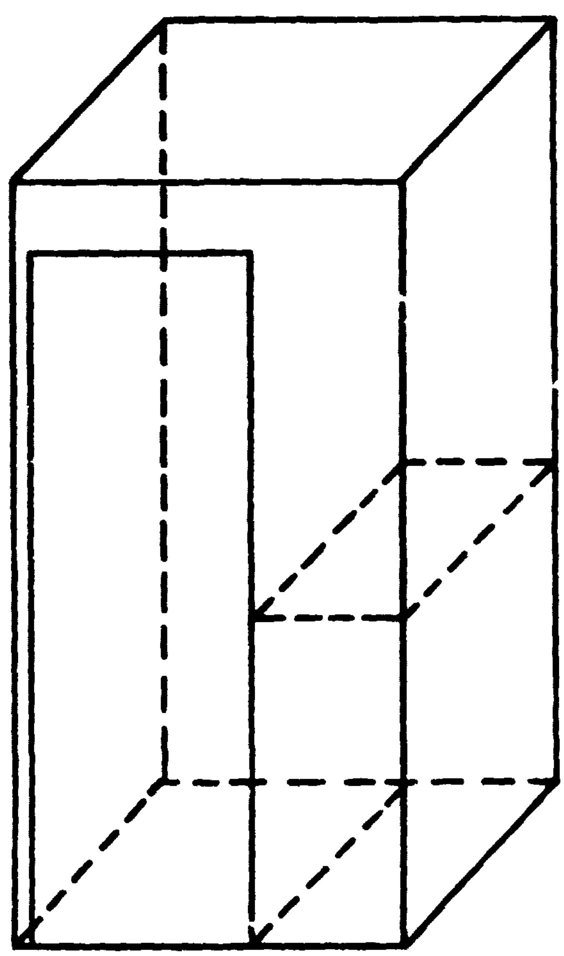
OVERVIEW

- BEGAN IN DECEMBER, 1977
- INTERIOR SANDWICH PANELS
- LAVATORY PANEL FABRICATION
  (NAS9 – 13000)
- INTERIOR PANEL FABRICATION
  (NAS2 – 10004)

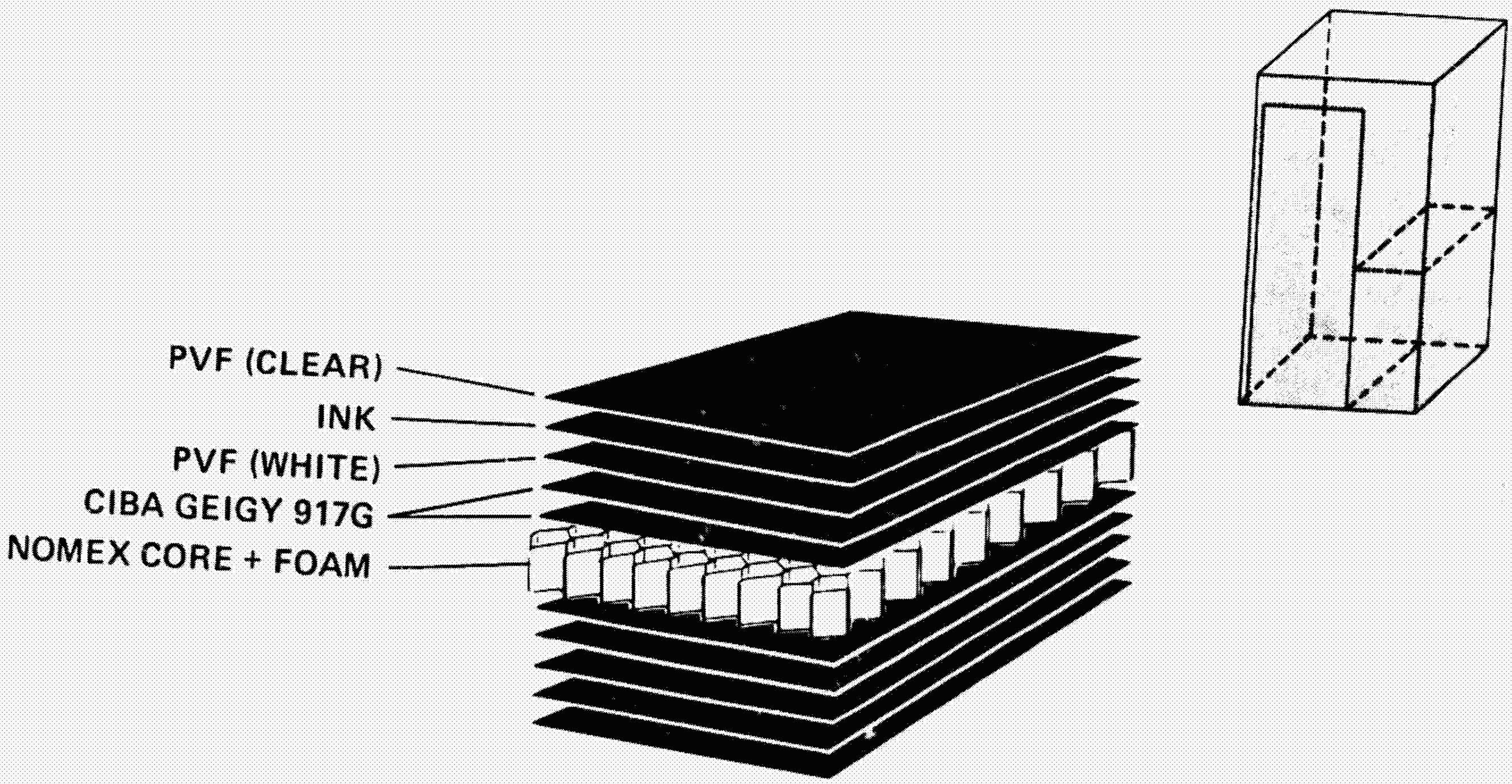
LAVATORY PANEL FABRICATION

- NASA-JSC
- 9 PANELS
- DC-10 LAVATORY SIMULATION

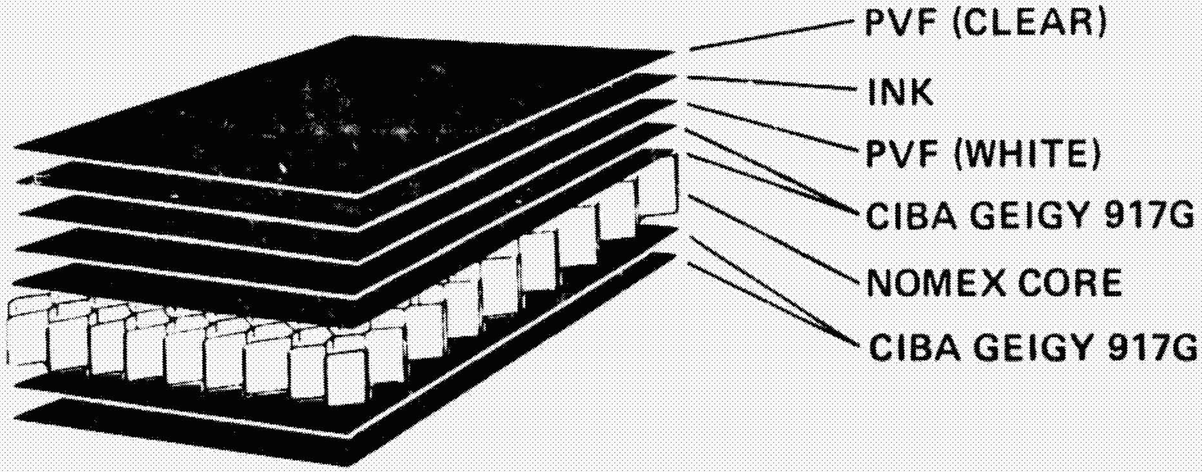
LAVATORY SCHEMATIC

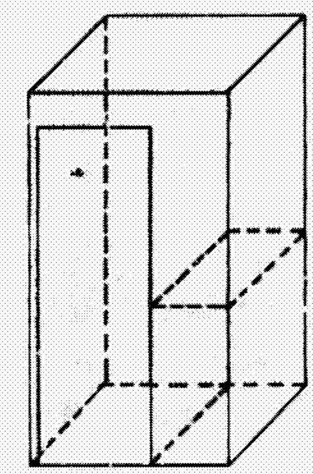


DOUBLE DECORATED PANEL

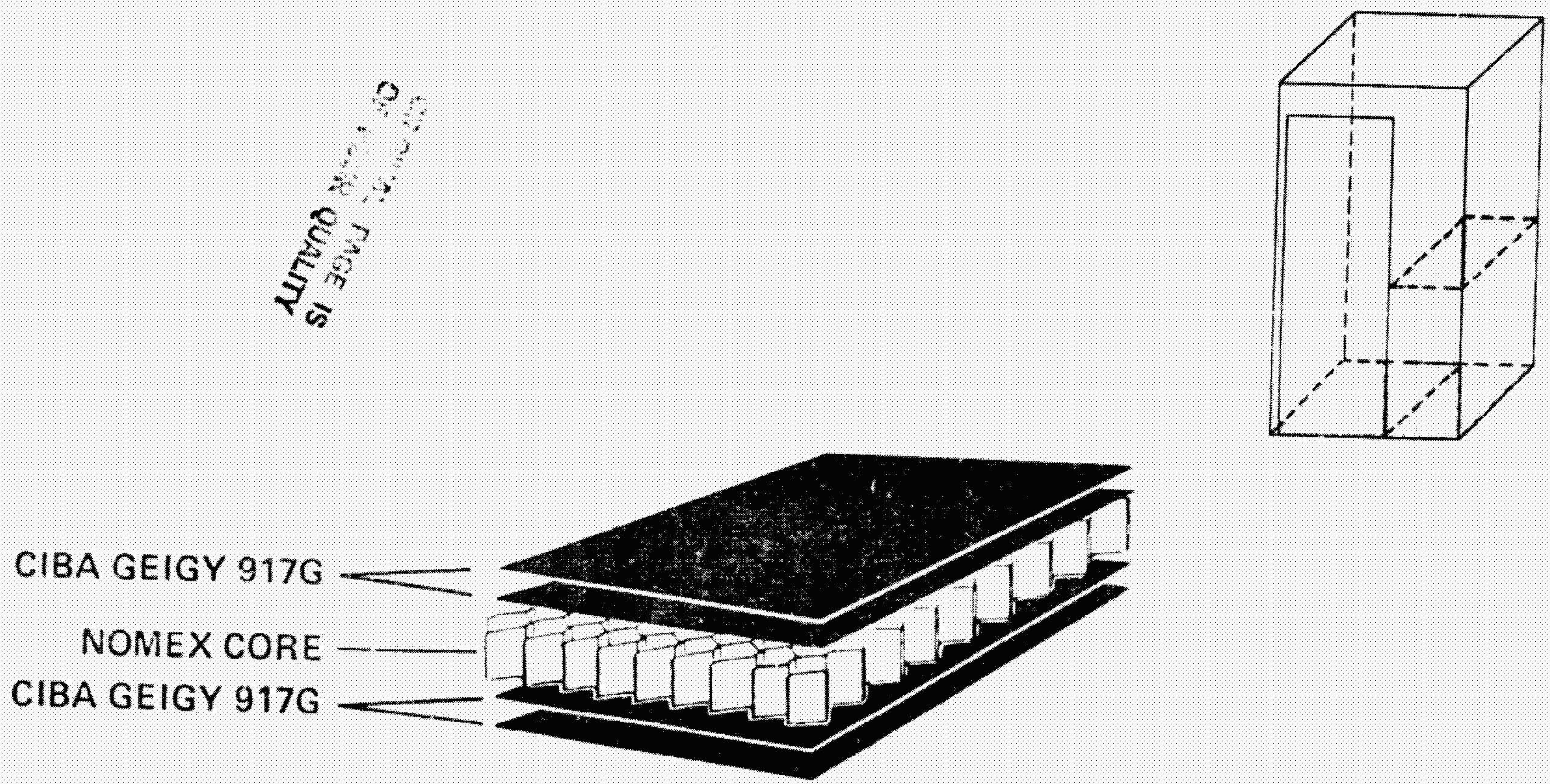


SINGLE DECORATED PANEL





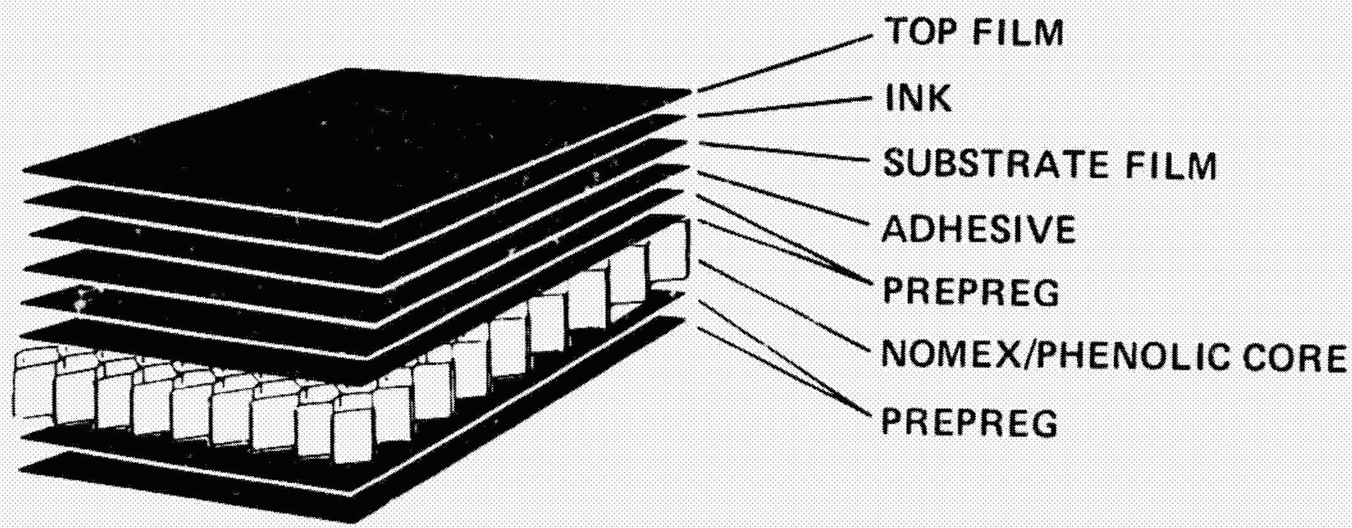
UNDECORATED PANEL



INTERIOR PANEL FABRICATION

- NASA-ARC
- 56 PANELS
- 40 X 96 X 1 INCH
- FAA-NAFEC
- VARIOUS THERMOPLASTIC FILMS

PANEL MAKEUP



PANEL MATERIALS

DECORATIVE FILM			ADHESIVE	PREPREG	
TOP	INK	SUBSTRATE		181	120
1 MIL PVF	ACRYLIC	2 MIL PVF	–	EPOXY	EPOXY
1 MIL PVF +3 MIL PVC	ACRYLIC	2 MIL PVF	TF-252	EPOXY	EPOXY
–	–	3 MIL PC	TF-252	PHENOLIC	PHENOLIC
1 MIL PVF	–	2 MIL PVF	TF-252	PHENOLIC	PHENOLIC
1 MIL PVF	–	5 MIL PC	TF-252	PHENOLIC	PHENOLIC
–	–	3 MIL PVF_2	TF-252	PHENOLIC	PHENOLIC
–	–	3 MIL PES	TF-252	PHENOLIC	PHENOLIC
1 MIL PVF	ACRYLIC	2 MIL PVF	TF-252	PHENOLIC	PHENOLIC

N79-31179

D/3

ADVANCED RESIN MATRICES FOR COMPOSITES

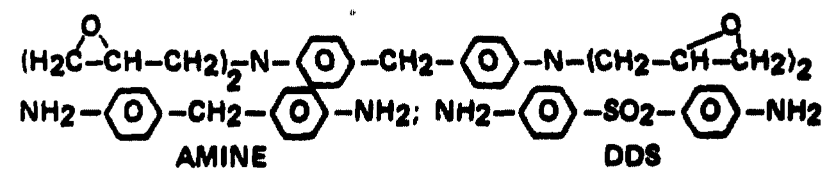
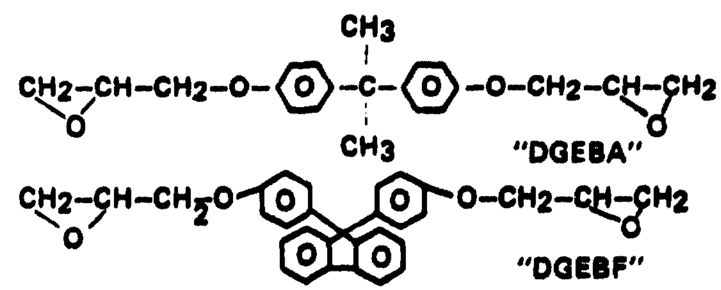
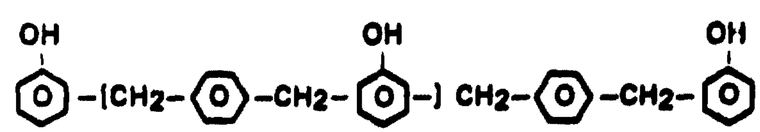
A PRESENTATION MADE AT
THE FIREMEN MEETING
SEATTLE, WASHINGTON
MARCH 2, 1979

D. A. KOURTIDES
NASA - ARC

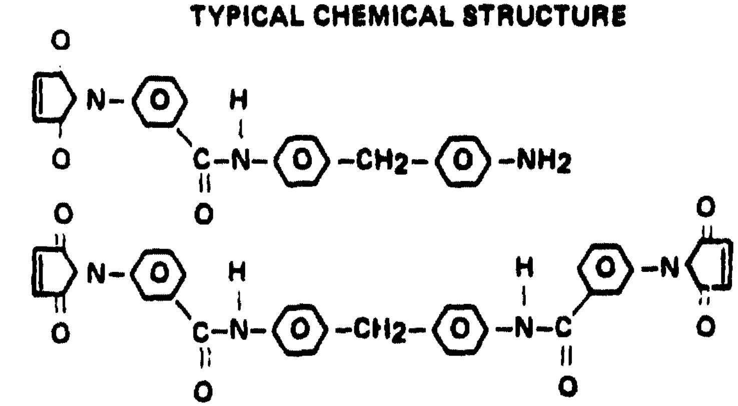
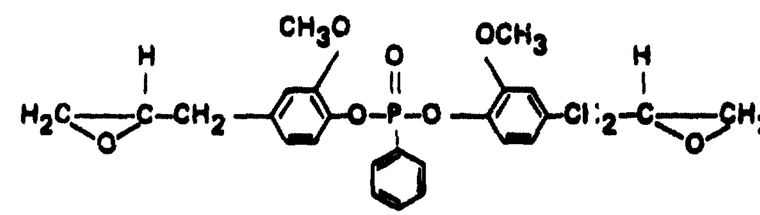
SELECTION CRITERIA FOR RESIN MATRICES

- HIGH CHAR YIELD
- HIGH OI, LOW SMOKE & TOXICITY
- GOOD ELEVATED TEMPERATURE MECHANICAL PROPERTIES
- GOOD THERMAL OXIDATIVE STABILITY
- HIGH HUMIDITY RESISTANCE
- CHEMICAL AND RADIATION RESISTANCE
- GOOD FATIGUE AND TOUGHNESS PROPERTIES
- COMPATIBLE PROCESSING, QUALITY CONTROL, AVAILABILITY AND COST TO STATE-OF-THE ART EPOXY RESINS

RESIN MATRICES FOR COMPOSITES

RESIN/CURING AGENT	TYPICAL CHEMICAL STRUCTURE
EPOXY RESIN BASED ON METHYLENE DIANILINE CURED WITH AROMATIC AMINE OR 4,4′ DIAMINO DIPHENYL SULPHONE (DDS) (SAMPLE 1)	
EPOXY RESIN BASED ON DIGLYCIDYL ETHER OF BISPHENOL A (DGEBA) OR 9,9-BIS-(4-HYDROXYPHENYL) FLUORENE (DGEBF) OR BLENDS CURED WITH TRIMETHOXYBOROXINE (TMB) OR MDA OR DDS (SAMPLE 2)	
PHENOLIC NOVOLAC RESIN BASED ON CONDENSATION OF DIMETHOXY-P-XYLENE AND PHENOL CURED WITH HEXAMINE (SAMPLE 3)	

RESIN MATRICES FOR COMPOSITES

RESIN CURING AGENT	TYPICAL CHEMICAL STRUCTURE
POLYBISMALEIMIDE PREPOLYMER (SAMPLE 4)	
BIS(4-GLYCIDYL-2-METHOXYPHENYL)PHENYLPHOSPONATE EPOXY RESIN CURED WITH N,N-DIETHYLAMINOPROPYLAMINE (DEAPA) (SAMPLE 5)	

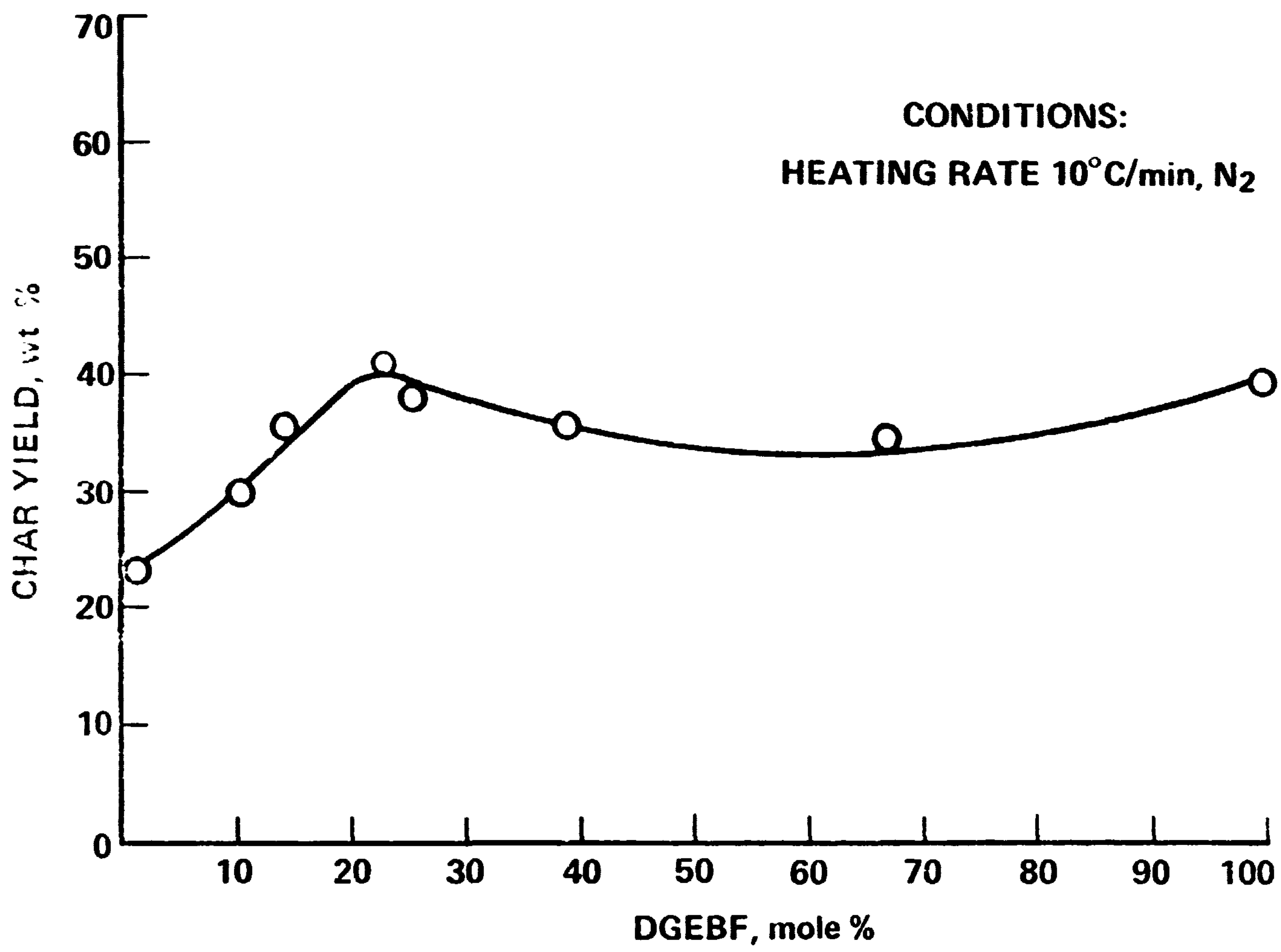
PROCESSING CONDITIONS FOR RESINS AND LAMINATES

RESIN	PURE RESIN		
	CATALYST	CURE	POST CURE
EPOXY RESIN (SAMPLE 1)	NMA OR DEAPA OR DDS	DDS, 30 pph, 150°C – 1 hr	190°C – 4 hrs
EPOXY RESIN, DGEBA/DGEBF (SAMPLE 2)	TMB OR DDS	TMB, 30 pph, 135°C – 3 hrs	180°C – 3 hrs 218°C – 3 hrs, N_2
RESIN/SOLVENT	**LAMINATE**		
	PREPREG	CURE	POST CURE
(SAMPLE 1)/MEK	AIR DRY, 80°C – 10 min 120°C – 20 min	163°C – 10 min, 340 KN/m^2 – 2 hrs	190°C – 4 hrs
(SAMPLE 2)/MEK	AIR DRY, 100°C – 15 min 140°C – 20 min	200°C – 10 min 340 KN/m^2 – 2 hrs	218°C – 3 hrs, N_2

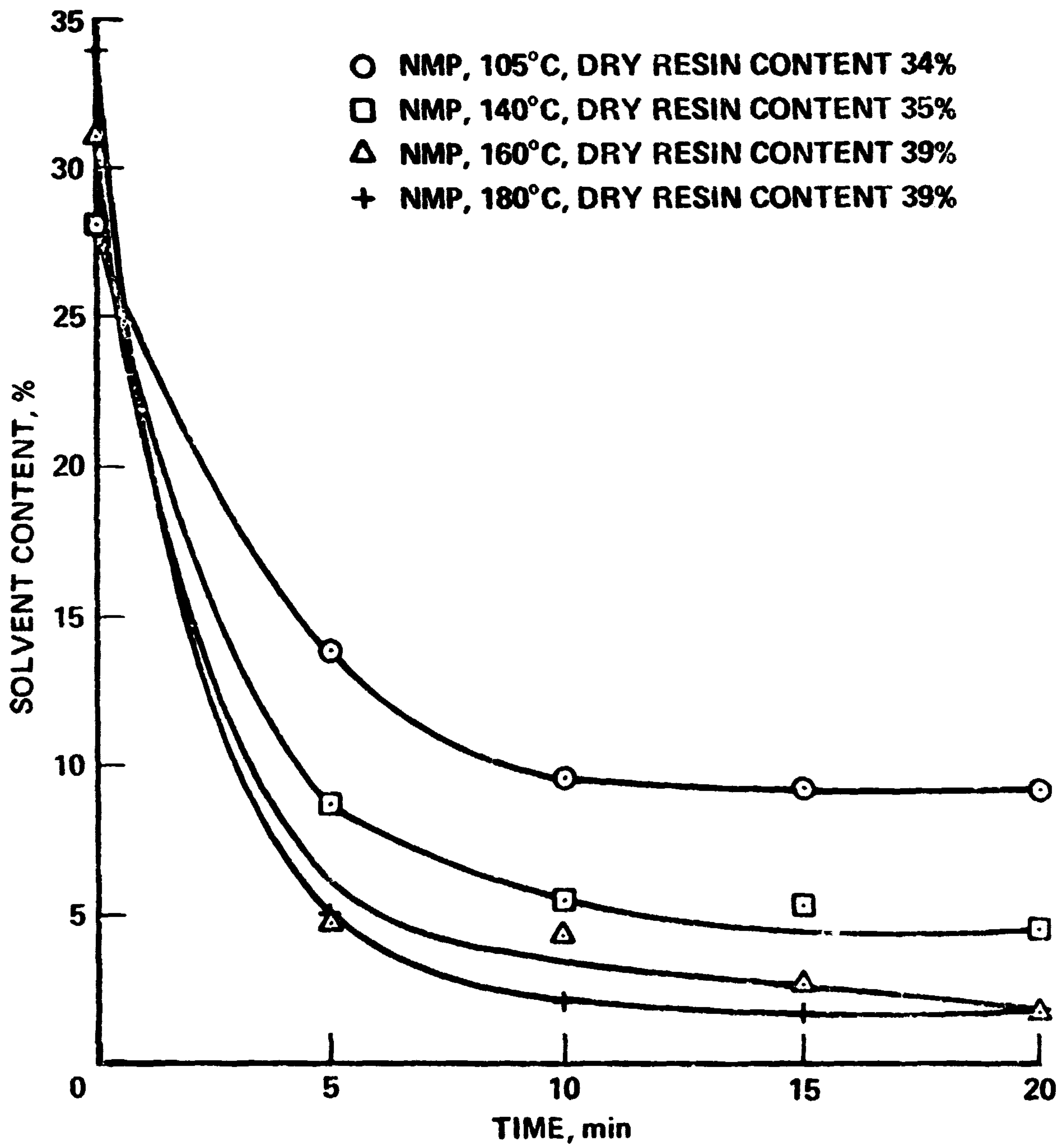
PROCESSING CONDITIONS FOR RESINS AND LAMINATES

RESIN	PURE RESIN		
	CATALYST	CURE	POST CURE
PHENOLIC NOVOLAC (SAMPLE 3)		160°C – 1.5 hrs	200°C – 1 hr
POLYBISMALEIMIDE (SAMPLE 4)		200°C – 3 hrs	
PHOSPHORYLATED EPOXY (SAMPLE 5)	DEAPA	DEAPA/ BAPMP	180°C – 4 hrs
RESIN/SOLVENT	LAMINATE		
	PREPREG	CURE	POST CURE
(SAMPLE 3)/MEK	65°C – 15 min 115°C – 20 min	177°C – 1 hr 680 KN/m^2	188°C – 2 hrs
(SAMPLE 4)/MEK	AIR DRY, 79°C – 15 min 120°C – 20 min	200°C – 3 hrs 680 KN/m^2	
(SAMPLE 5)/MEK	AIR DRY, 80°C – 10 min 120°C – 20 min	180°C – 10 min	200°C – 4 hrs

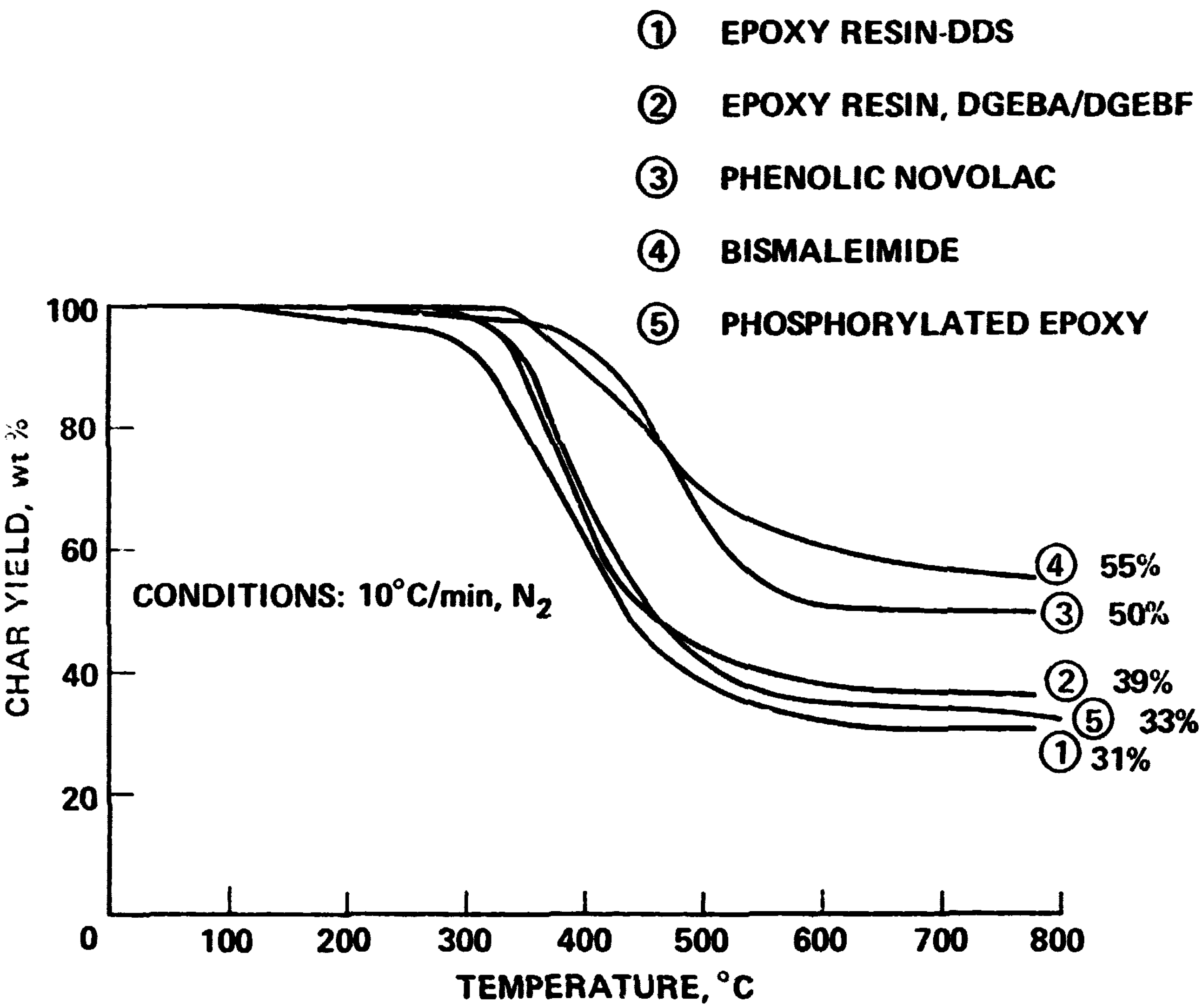
EFFECT OF DGEBF MOLE FRACTION IN THE BLEND OF DGEBA/DGEBF ON THE CHAR YIELD OF THE COPOLYMER AT 700°C



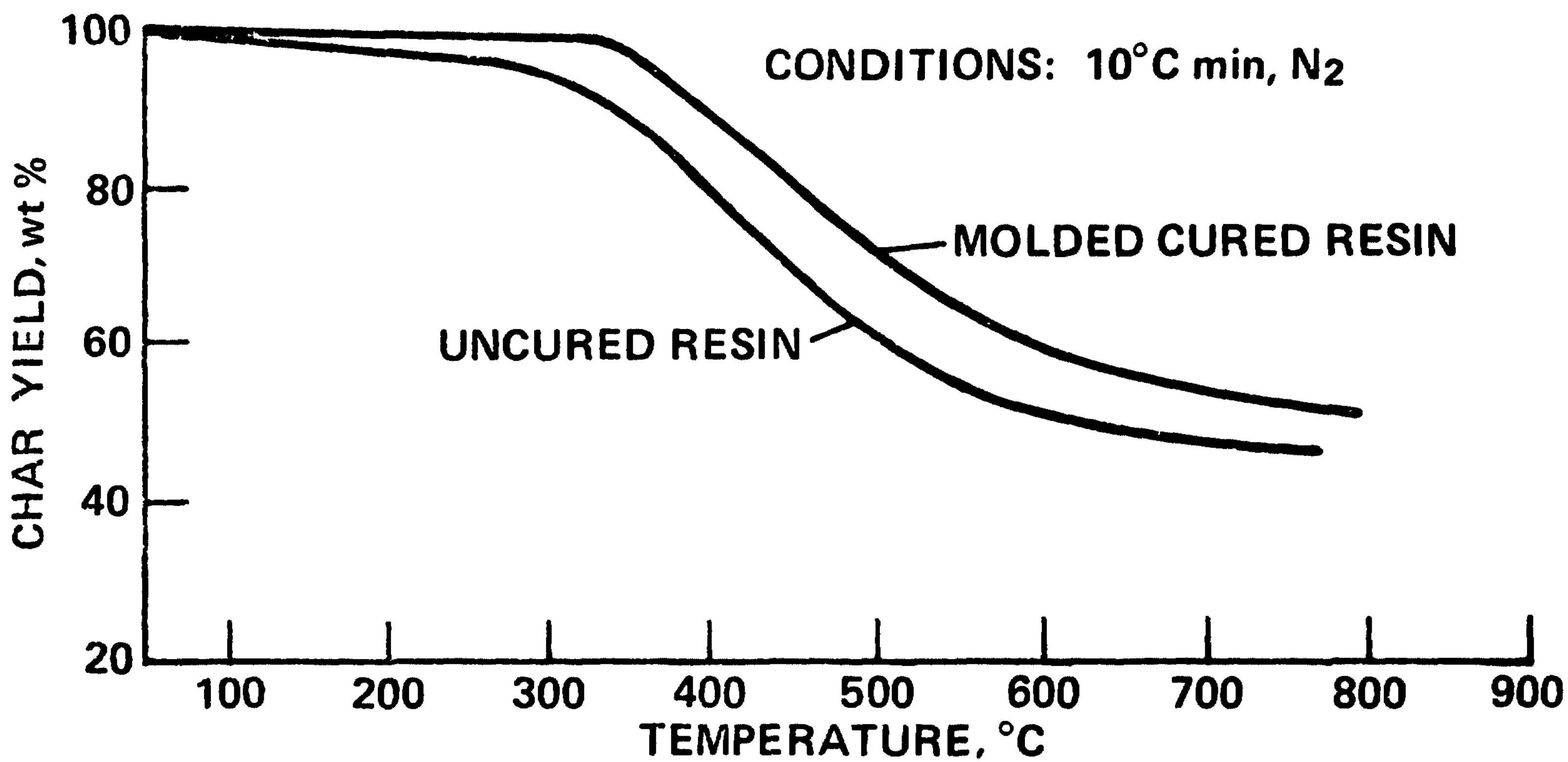
DRYING CURVES FOR BISMALEIMIDE/181-PREPREGS



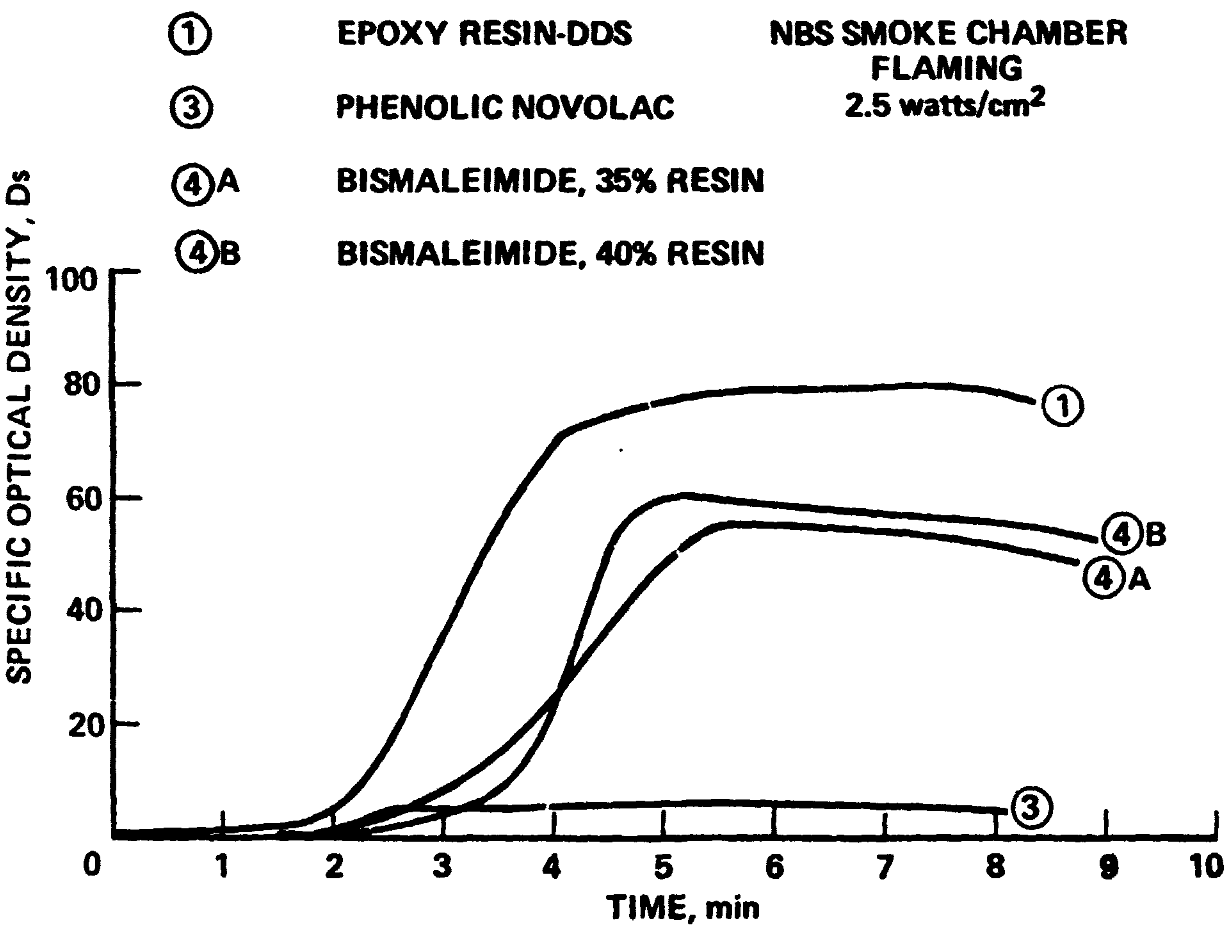
DYNAMIC THERMOGRAVIMETRIC ANALYSES OF RESINS



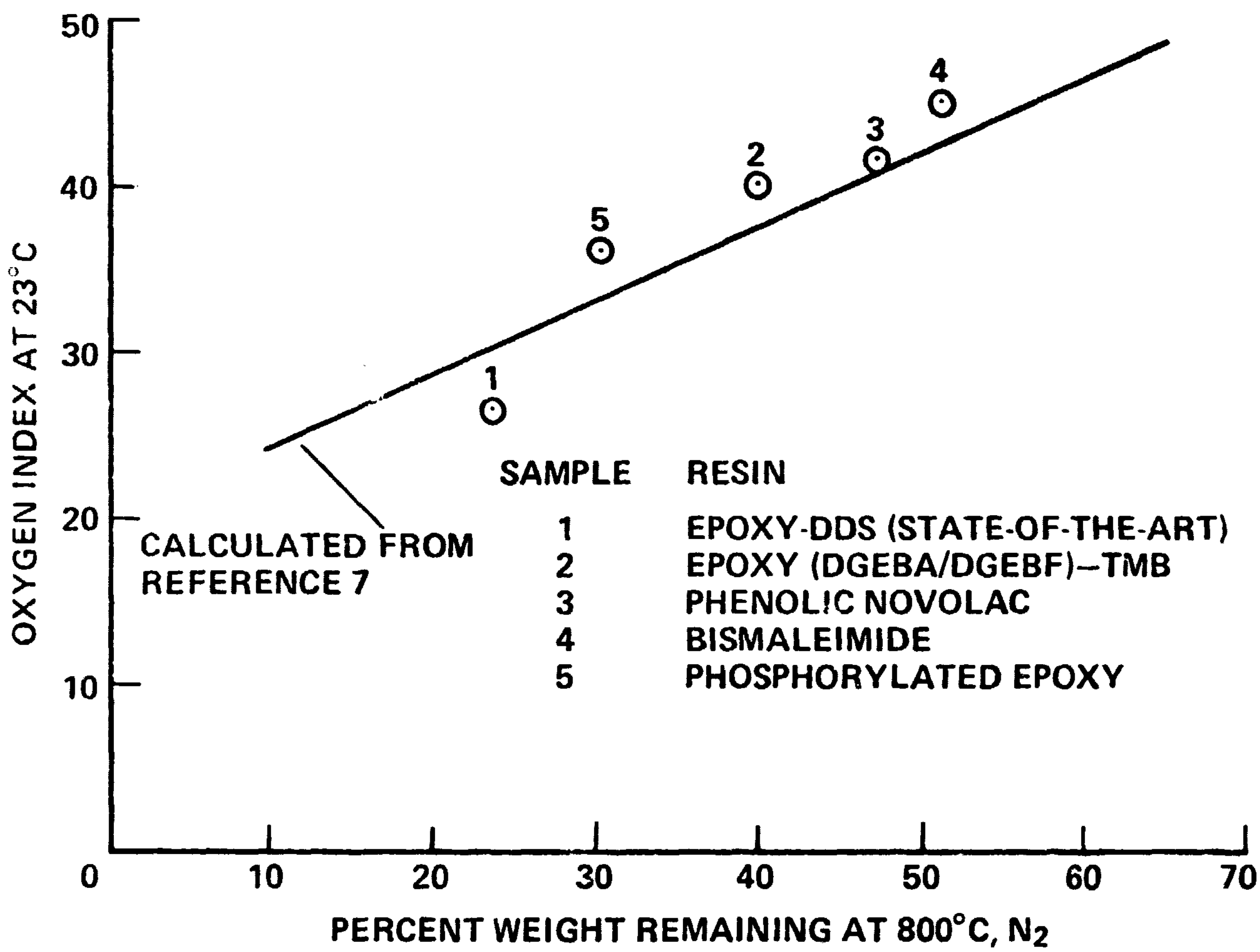
DYNAMIC THERMOGRAVIMETRIC ANALYSIS OF BISMALEIMIDE RESIN (SAMPLE 5)



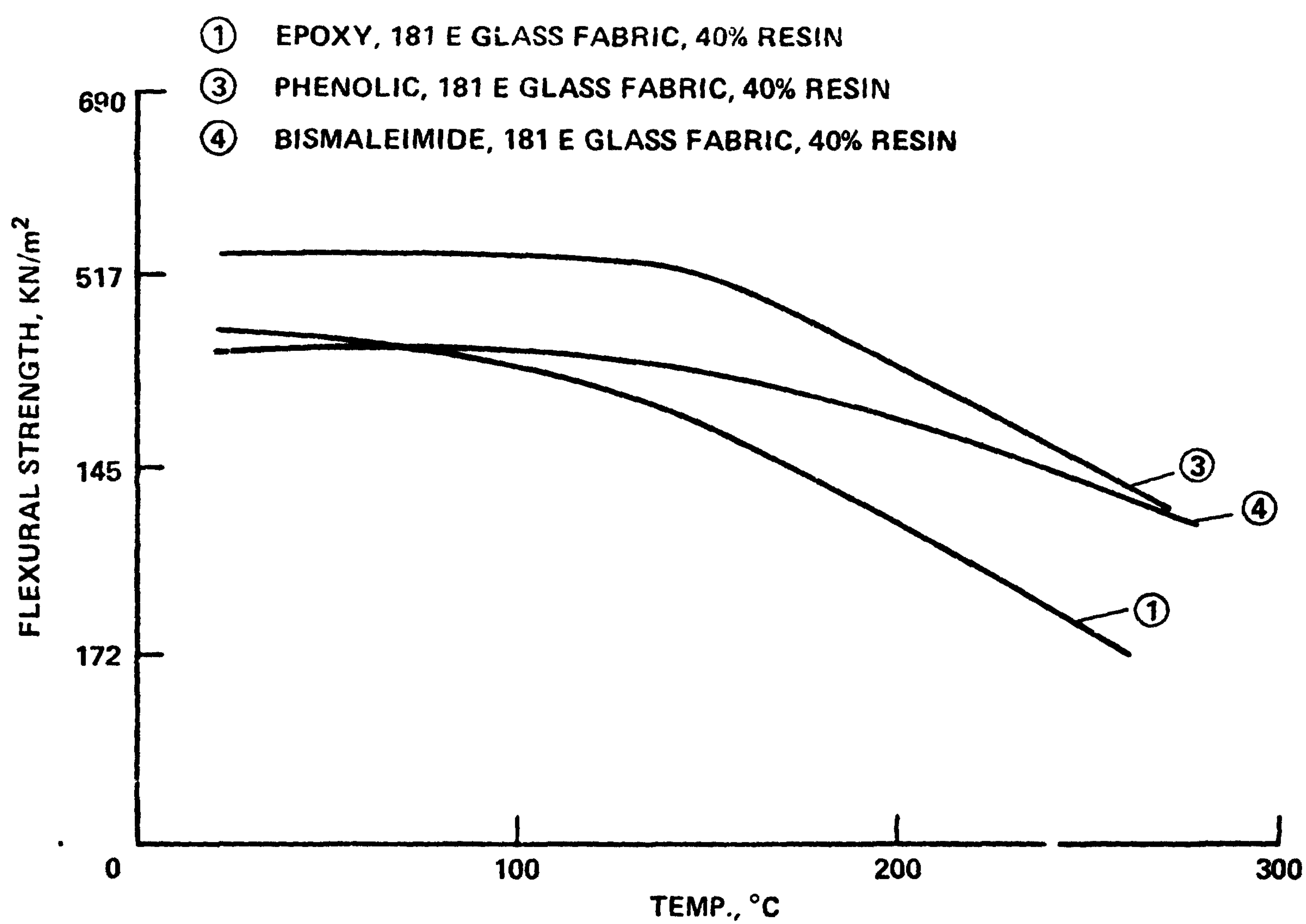
SMOKE EVOLUTION OF RESIN/181 GLASS LAMINATES



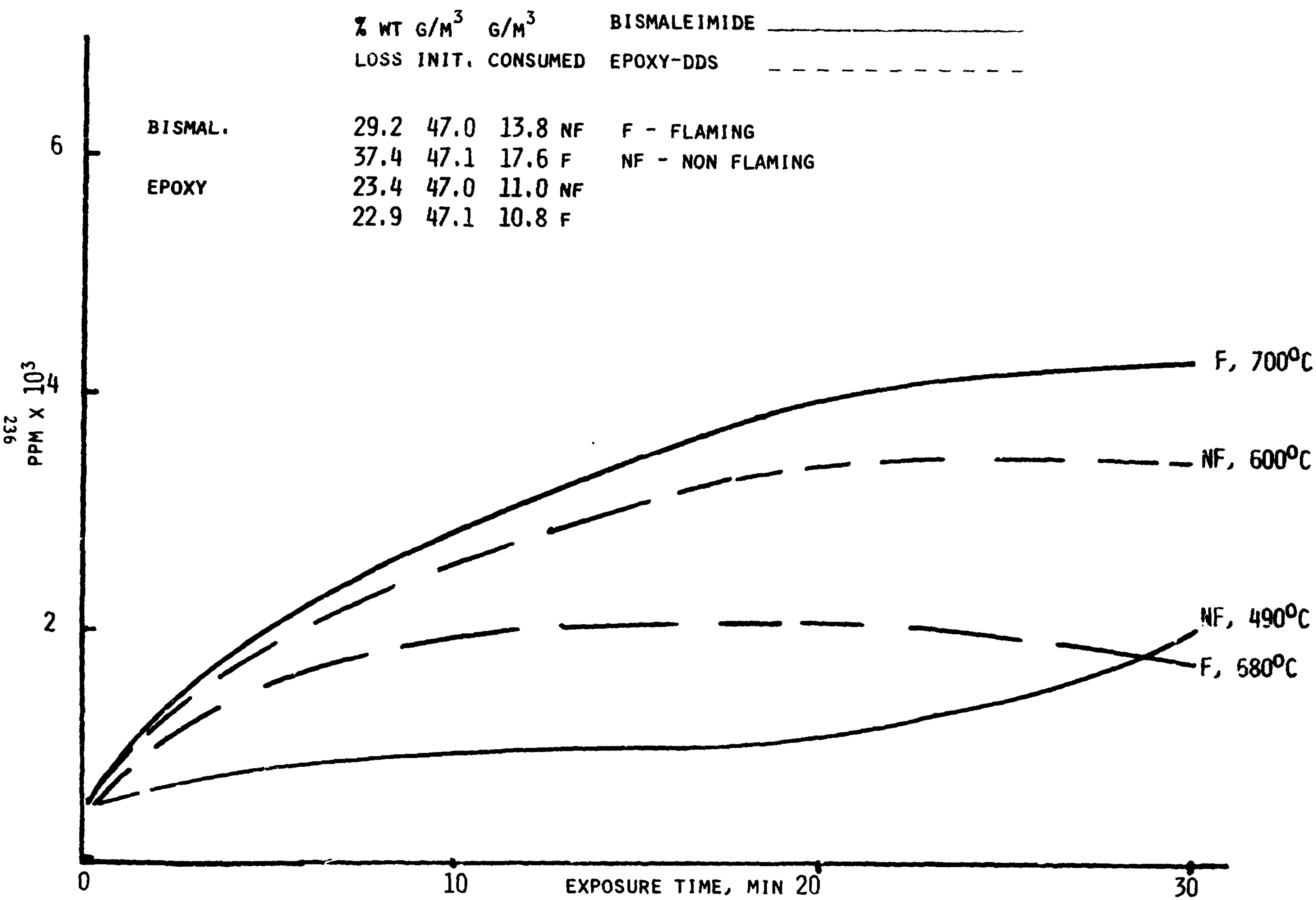
EFFECT OF CHAR YIELD OF THERMOSET POLYMERS ON OXYGEN INDEX



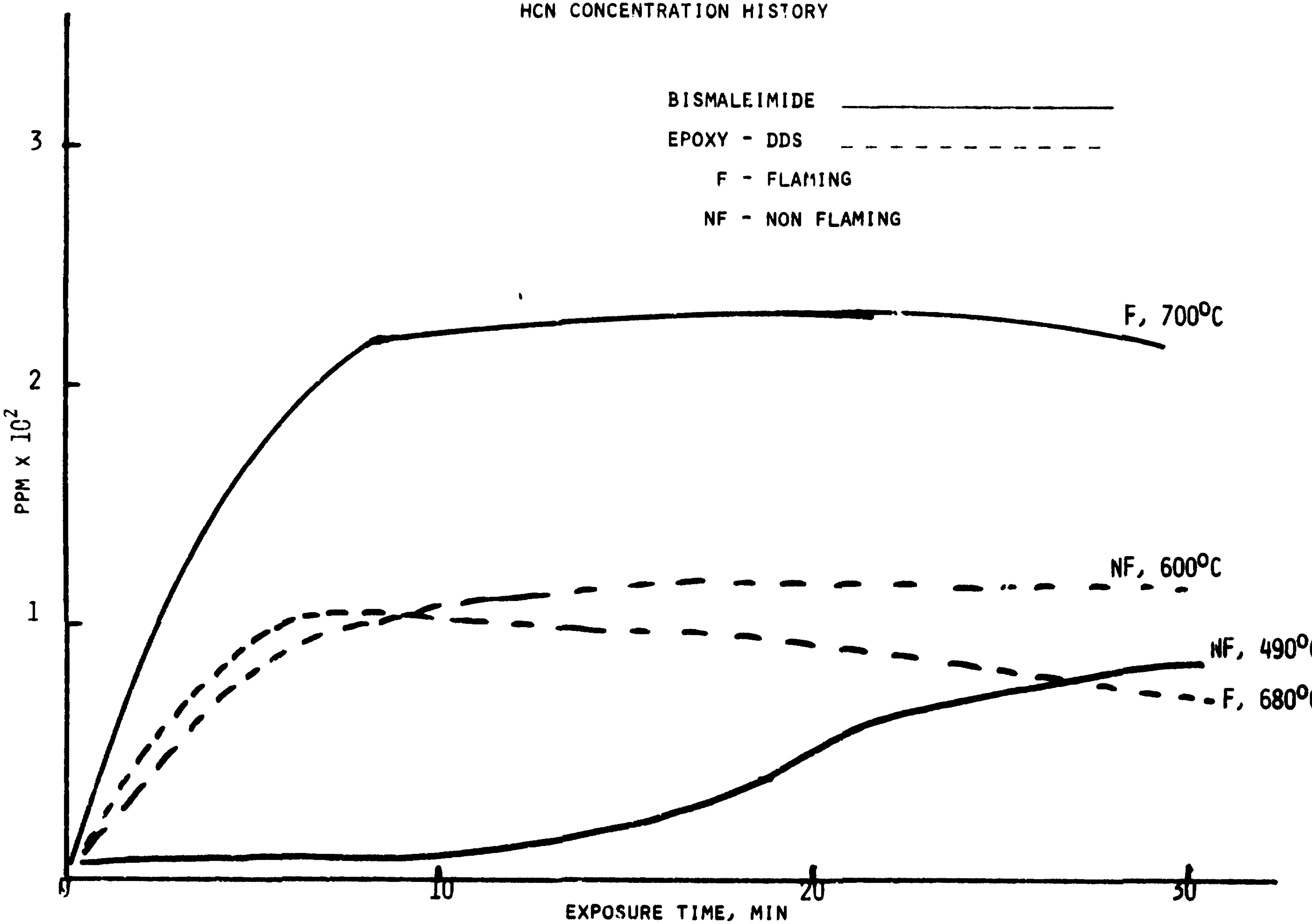
EFFECT OF TEMPERATURE ON FLEXURAL STRENGTH OF COMPOSITES



CO CONCENTRATION HISTORY



HCN CONCENTRATION HISTORY



CONCLUSIONS

DGEBA/DGEBF EPOXY CURED WITH TMB EXHIBITED HIGHEST OI AND γ_C THAN ALL OTHER EPOXY RESINS WITH PROCESSING PARAMETERS COMPARABLE TO CONVENTIONAL EPOXIES.

PHENOLIC-NOVOLAC RESIN EXHIBITED LOWEST Ds THAN ALL OTHER RESIN SYSTEMS.

BISMALEIMIDE RESIN EXHIBITED HIGHEST OI AND γ_C THAN ALL OTHER RESIN SYSTEMS. PROCESSING PARAMETERS COMPARABLE TO PHENOLICS.

ABOVE RESINS EXCELLENT CANDIDATES FOR RESIN MATRICES FOR GLASS OR GRAPHITE COMPOSITES.

D14

N79-31180

A COMPARATIVE STUDY OF THE TOXICITY OF THE COMBUSTION PRODUCTS OF TEDLAR AND A FLUORENONE-POLYESTER FILM

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University of Utah
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Salt Lake City, Utah 84108

INTROD' :TION

The relative toxicity in the rat resulting from a 30-minute exposure to the combustion products of two materials, Tedlar and a fluorenone-polyester film, has been assessed. The combustion products were generated into a static exposure system using a laboratory-scale furnace. The toxicity was assessed using the primary measurements employed in a more detailed overall toxicity evaluation. The endpoints employed in the assessment were incapacitation and death. The toxicological events observed during the 30-minute exposure are reported here. This report does not consider any post-exposure consequences of the exposure.

METHODS

Combustion of Materials

The sample sizes used in this study were chosen to produce nominal combustion product concentrations ranging from 5 to 40 grams per cubic meter. These concentrations were the quotient of the number of grams of sample introduced into the furnace divided by the chamber capacity (.064 m^3).

Exposure System

The exposure chamber used for these studies was of an octagonal configuration with a nominal volume of 60 ℓ. A circular port was present on each of four faces of the chamber, approximately 6" above the floor. Into these ports were inserted four male pigmented Long-Evans rats (350-450 gm) held in tubular restrainters, so that they could be exposed to the combustion atmosphere in a head-only fashion. The furnace and combustion conditions used in the study were those reported by Potts and

Lederer (1977). The materials were combusted in both the flaming and nonflaming modes. The furnace was mounted below the chamber such that the mouth of the furnace was essentially flush with the bottom of the chamber. The furnace held a Monel beaker in which the sample was combusted. A PTFE-coated cone was placed above the furnace to shield the animals from direct flame radiation, and to aid in convection of the combustion products.

Toxicological Evaluation

Rats were exposed to the combustion atmospheres for a period of 30 minutes. To determine incapacitation, all animals were monitored for performance of the leg-flexion avoidance response, using a method similar to that described by Packham *et al.* (1978).

Analysis of the combustion product atmosphere was carried out throughout each exposure. Combustion atmospheres were sampled at 3.5-minute intervals for CO, CO_2, and O_2, which were detected using gas chromatographic techniques. Temperatures inside the chamber were monitored utilizing a chromel-alumel thermocouple at the level of the animals, with an external reference cold junction and recorded on a strip chart recorder.

The ability of each material to generate CO under the conditions of the experiment was expressed as the CO-generating capacity (mg CO/gm material). This was calculated for each exposure using the following equation:

$$\underset{\text{(mg CO/gm material)}}{\text{CO-generating capacity}} = \frac{\text{ppm} \times \text{chamber vol. } (\ell) \times \text{M.W.} \times 10^{-3}}{\text{sample wt.} \times 25.79^{*}}$$

*mole volume in Salt Lake City

The relationship between the percentage of population affected versus concentration of combustion products (gm/m^3 of material introduced into the furnace) was established employing the statistical methodology described by Miller and Tainter (1944). This relationship was obtained for both incapacitation and death. The EC_{50} (concentration causing incapacitation in 50% of the population) and LC_{50} (concentration causing death in 50% of the population) were calculated for each material, under the two combustion conditions.

Animals surviving the exposure were subjected to a behavioral examination immediately post-exposure. This examination considered standard observations designed to determine their behavioral, motor coordination, central nervous system and autonomic capabilities. Blood samples were obtained by cardiac puncture from those animals that died during the exposure, and carboxyhemoglobin (COHb) levels were determined using an Instrumentation Laboratories 282 Co-Oximeter.

Animals surviving the exposure were retained for 14 days. During this post-exposure period they were weighed on a regular basis and any deaths occurring were recorded. Observations that were made during this period will be presented in an addendum to this report. This will include a re-calculation of the respective LC_{50} values based upon the total number of deaths observed both during the 30-minute exposure and the 14-day post-exposure period.

Materials

Both materials, Tedlar and the fluorenone-polyester film, were supplied by NASA-Ames Laboratory. Both materials were supplied as thin films. The Tedlar sample was opaque, and the fluorenone-polyester film was clear.

TABLE 1

THE INCAPACITATING AND LETHAL POTENCIES OF THE NONFLAMING AND FLAMING COMBUSTION PRODUCTS OF TEDLAR AND A FLUORENONE-POLYESTER FILM

Combustion Condition	Material	Furnace Temperature (°C)	CO Generation mg/gm	Incapacitation EC_{50} ± S.E.	Death (30 min.) LC_{50} ± S.E.
Nonflaming	Tedlar	700	101	18.8 ± 6.8	34.0*
	Fluorenone-polyester	720	240	10.9*	17.2
Flaming	Tedlar	800	47	21.0 ± 6.8	> 40
	Fluorenone-polyester	780	227	10.7 ± 0.8	13.2 ± 1.4

*insufficient data to calculate standard error (S.E.)

Carbon Monoxide Levels

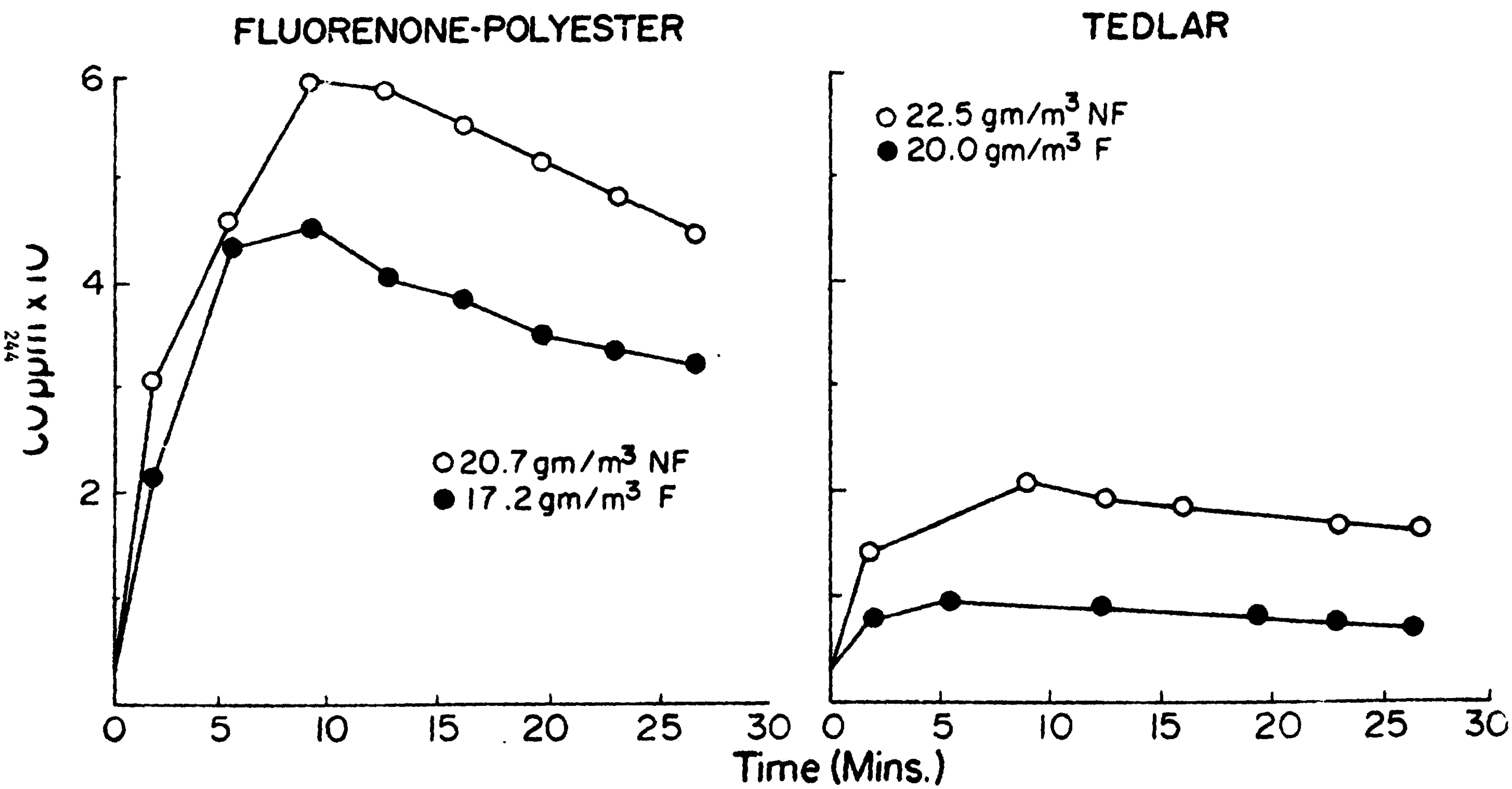


TABLE 5a

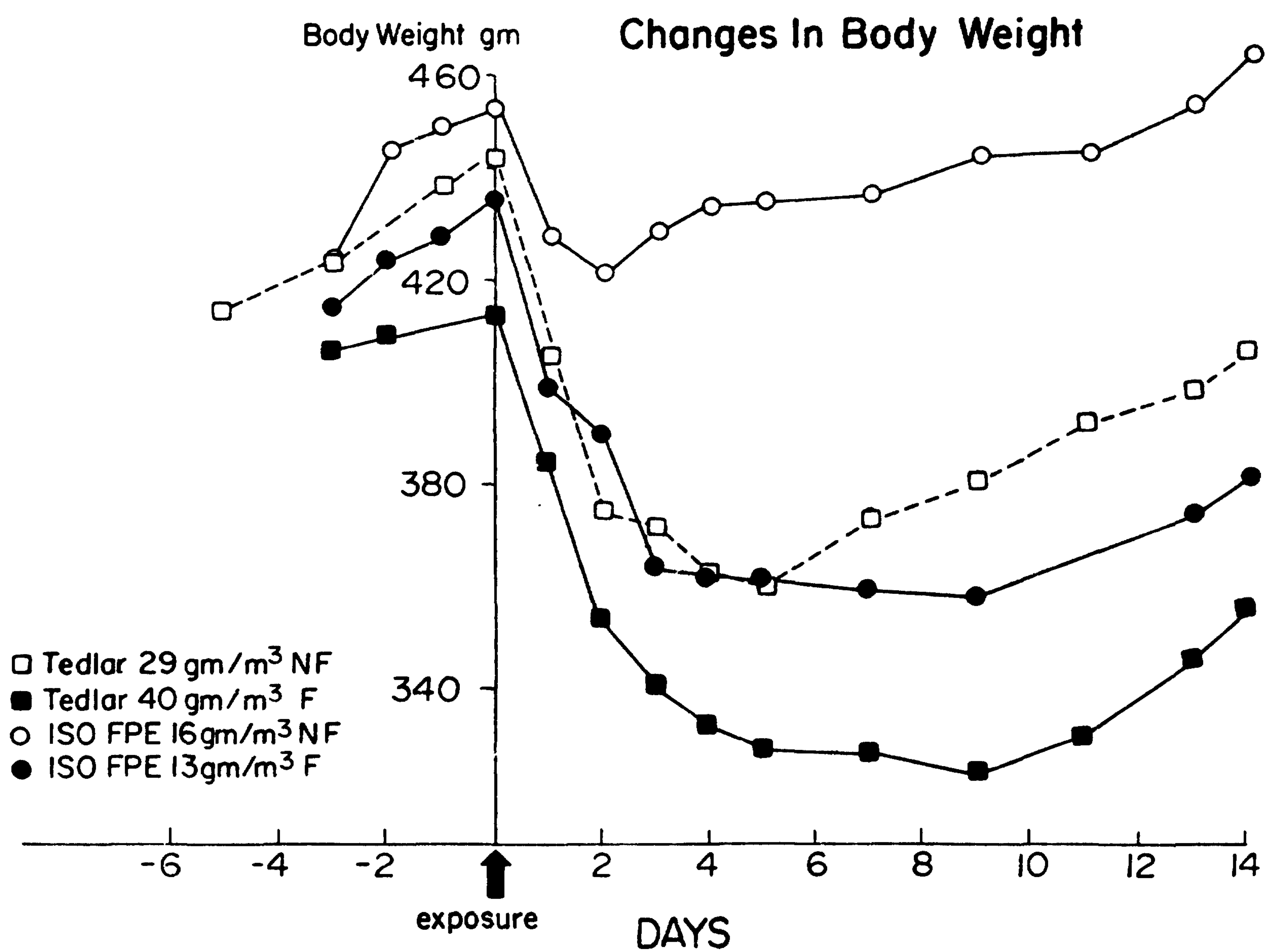
COMPARISON OF TOXICOLOGICAL OBSERVATIONS ON SURVIVING RATS EXPOSED TO THE NON-FLAMING COMBUSTION PRODUCTS OF A POLYESTER FILM AND POLYVINYL FLUORIDE FILM (PVF)

		Number of animal showing observation						
		Polyester film			PVF film			
Concentration gm/m^3		10.3	11.6	16.2	5.0	7.9	22.5	29.3
<u>Observations</u>								
Incapacitation		0	4	4	0	0	1	4
(mean time - secs.)		(-)	(1139)	(963)	-	-	(1735)	(701)
<u>Behavior</u>	n=	4	4	4	4	4	4	4
↓ activity		1	0	4	0	0	4	4
↑ sensitivity to touch		0	0	0	0	0	0	0
↓ pain (tail pinch)		0	0	3	0	0	0	3
↓ nuzzle response		1	1	4	0	0	0	0
<u>Motor Coordination</u>								
↓ righting reflex		2	3	3	0	1	2	4
↓ hang response		0	4	3	0	0	2	3
↓ posture		1	3	4	0	0	4	2
↓ muscle tone		4	4	4	0	0	4	3

TABLE 5b

COMPARISON OF TOXICOLOGICAL OBSERVATIONS ON SURVIVING RATS EXPOSED TO THE NON-FLAMING COMBUSTION PRODUCTS OF A POLYESTER FILM AND POLYVINYL FLUORIDE FILM (PVF)

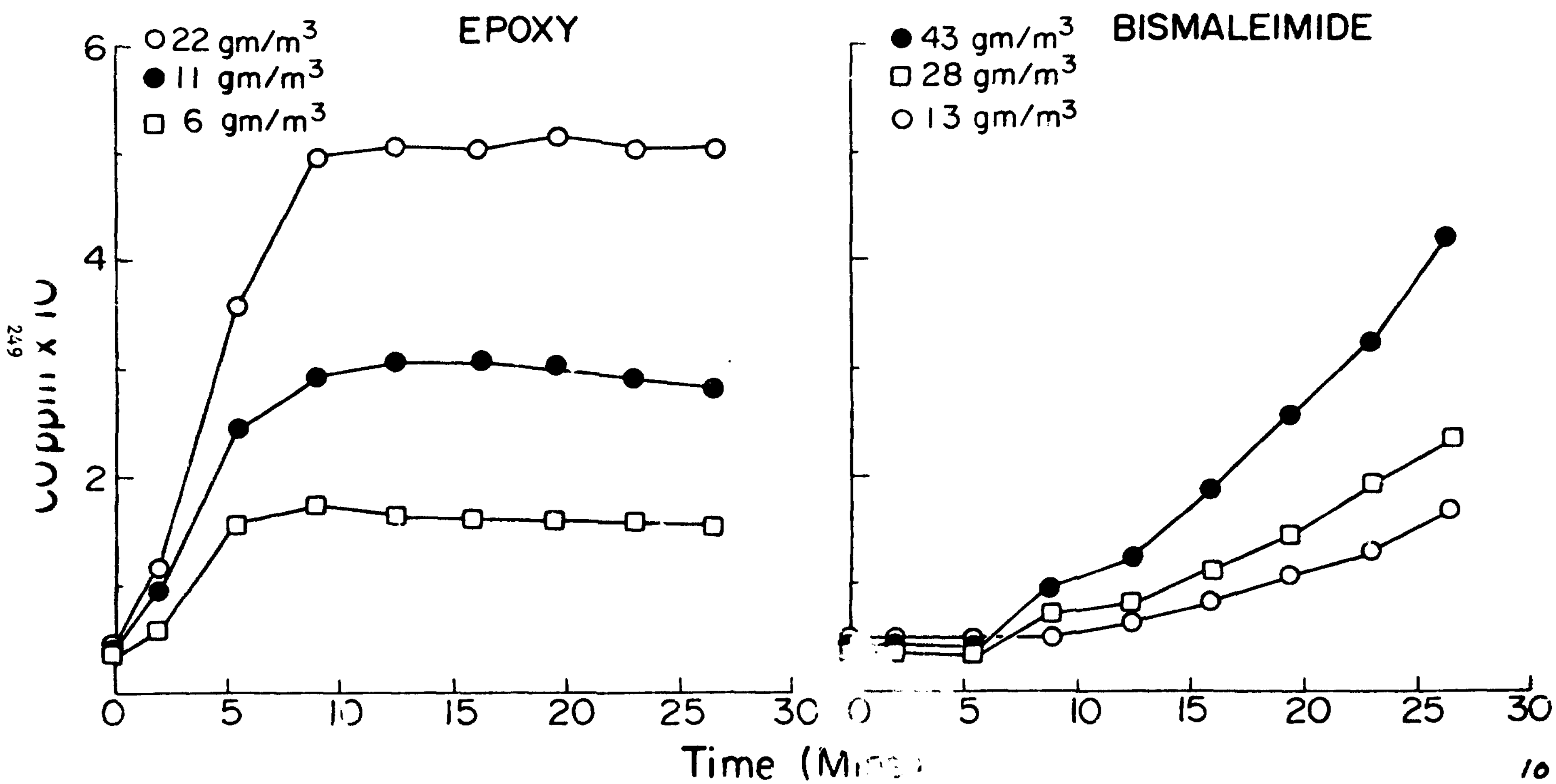
	Number of animals showing observation						
	Polyester film			PVF film			
Concentration gm/m^3	10.3	11.6	16.2	5.0	7.9	22.5	29.3
CNS							
↓ startle response	0	0	0	0	0	1	3
tremors, twitches, convulsions	0	0	0	0	0	0	0
Autonomic							
eyes - ↓ corneal reflex	0	0	0	0	0	0	0
↑ lachrymation	3	0	2	2	4	4	4
↓ clarity	0	0	3	0	0	4	4
salivation	0	1	1	1	4	2	3
nasal discharge	1	1	0	0	4	4	3
visible respiration - abnormal	4	1	4	0	2	2	4



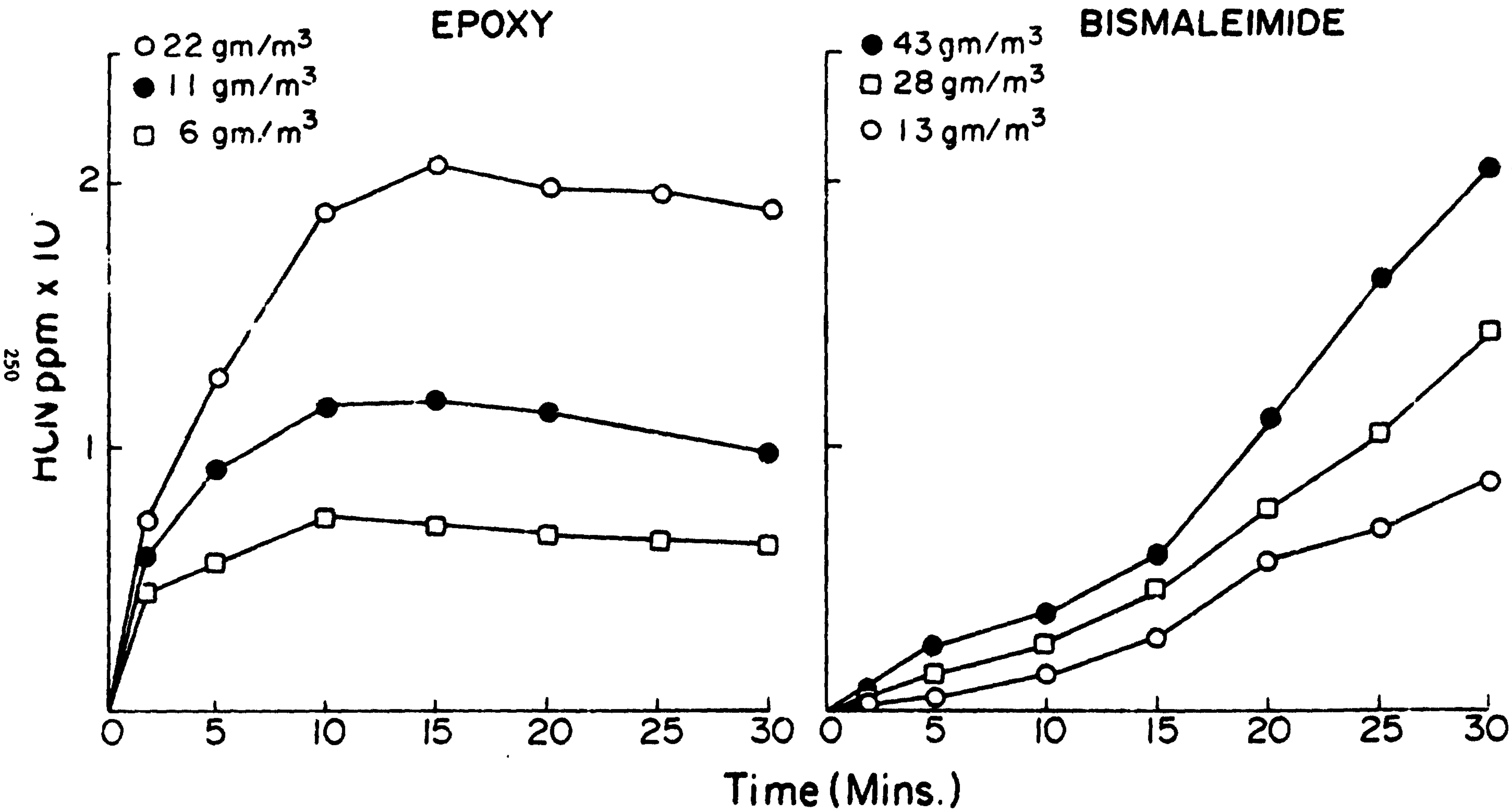
Changes In Body Weight
Body Weight gm
460
420
380
340
-6
-4
-2
2
4
6
8
10
12
14
exposure
DAYS
Tedlar 29 gm/m3 NF
Tedlar 40 gm/m3 F
ISO FPE 16gm/m3 NF
ISO FPE 13gm/m3 F

Material	Combustion Condition	Furnace Temperature	CO generated mg/gm	HCN generated mg/gm	EC_{50} ± S.E.	LC_{50} ± S.E.
EPOXY	NF	600°C	74.6 ± 10.7 n=8	3.2 ± 0.7 n=10	4.14 ± 0.87	11.01 ± 2.09
	F	680°C	50.5 ± 13.1 n=8	2.5 ± 0.6 n=8	6.23 ± 1.04	7.26
BISMALEIMIDE	NF	490°C	27.5 ± 5.2 n=9	1.4 ± 0.3 n=9	20.13 ± 3.88	41.85 ± 3.16
	F	700°C	85.6 ± 8.7 n=10	2.9 ± 0.9 n=10	6.83 ± 1.45	14.98 ± 2.22

Carbon Monoxide Generation From Non-Flaming Combustion of Resins



Hyrodogen Cyanide Generation From Non-Flaming Combustion of Resins



N79-31181

FIRE AND SMOKE RETARDANT MATERIALS DEVELOPMENT

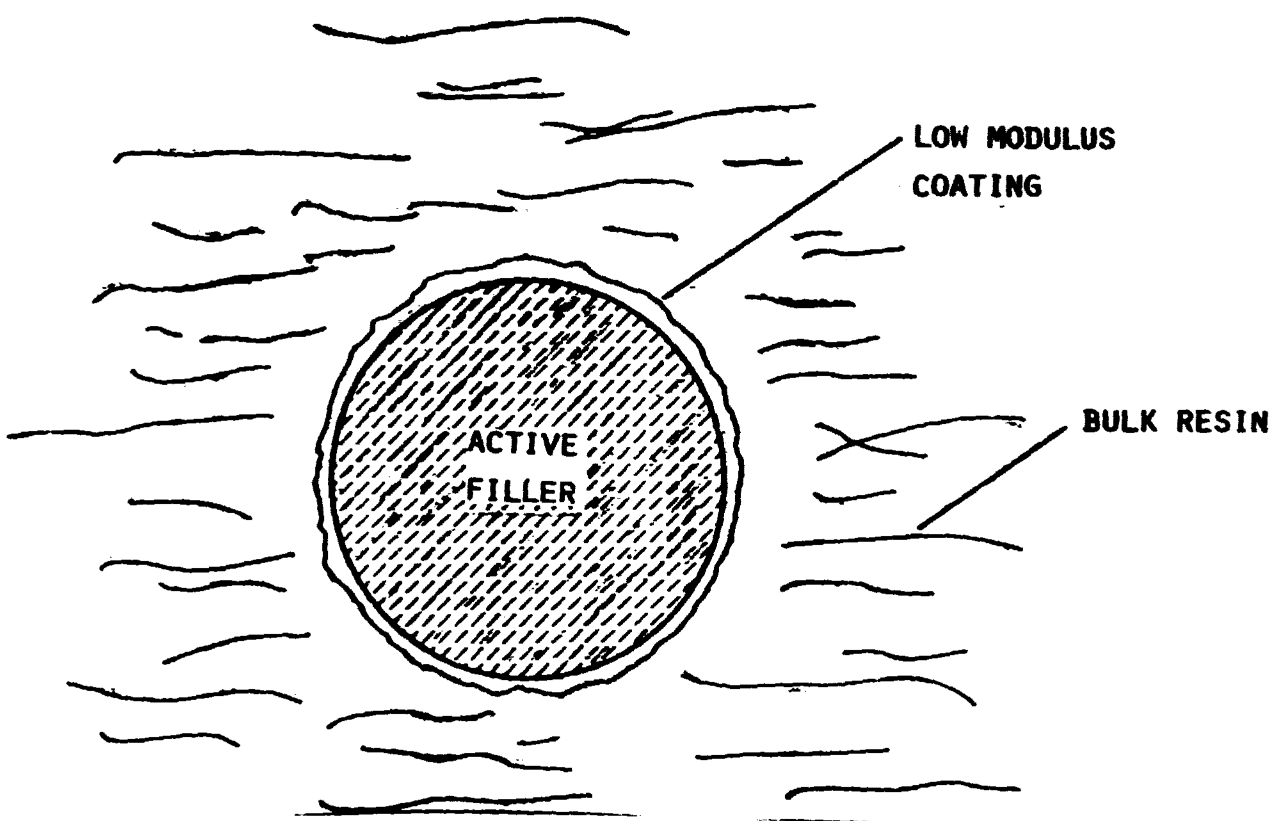
W.A. Mueller

ORIGINAL PAGE IS
OF POOR QUALITY

FLAME AND SMOKE RETARDANCE IN PLASTICS MAY BE OBTAINED BY USING INHERENTLY NONFLAMMABLE RESINS, BY THE USE OF ADDITIVES, AND BY USING FILLERS. ACTIVE FILLERS ABSORB HEAT AND RELEASE COOLING GASES SUCH AS WATER VAPOR. THE USE OF FILLERS ALTERS PHYSICAL PROPERTIES, AND, IN PARTICULAR, CAUSES A DECREASE IN IMPACT RESISTANCE, AN ESSENTIAL PROPERTY OF MOLDED PARTS FOR AIRCRAFT INTERIORS. THE PRESENT RESEARCH SEEKS TO PROVIDE A MECHANISM FOR DISSIPATION OF IMPACT ENERGY IN FILLED POLYMERS BY USING FILLERS WITH A LOW MODULUS COATING WHICH WILL DISSIPATE ENERGY THROUGH SHEARING AND CRAZING INSTEAD OF FRACTURE. THE APPROACH OFFERS THE ADVANTAGES OF LOW COST, LOW TOXICITY, AND APPLICABILITY TO VARIOUS RESINS.

SEVERAL METHODS MAY BE USED TO APPLY COATING TO FILLER. FOR MINERAL FILLERS WITH ALKALINE SURFACES, INCORPORATION OF SMALL AMOUNTS OF ACIDIC SITES IN THE COATING AFFORDS READY BONDING BETWEEN THE TWO MATERIALS. A COPOLYMER OF 2-ETHYLHEXYL ACRYLATE (EHA) AND ACRYLIC ACID (AA) HAS BEEN SYNTHESIZED AND EVALUATED. IT IS CROSSLINKED BY THE FILLER PARTICLES, PROVIDING A RUBBERY MATERIAL AND SOME CONTROL OVER MODULUS.

FILLER PARTICLE SCHEMATIC

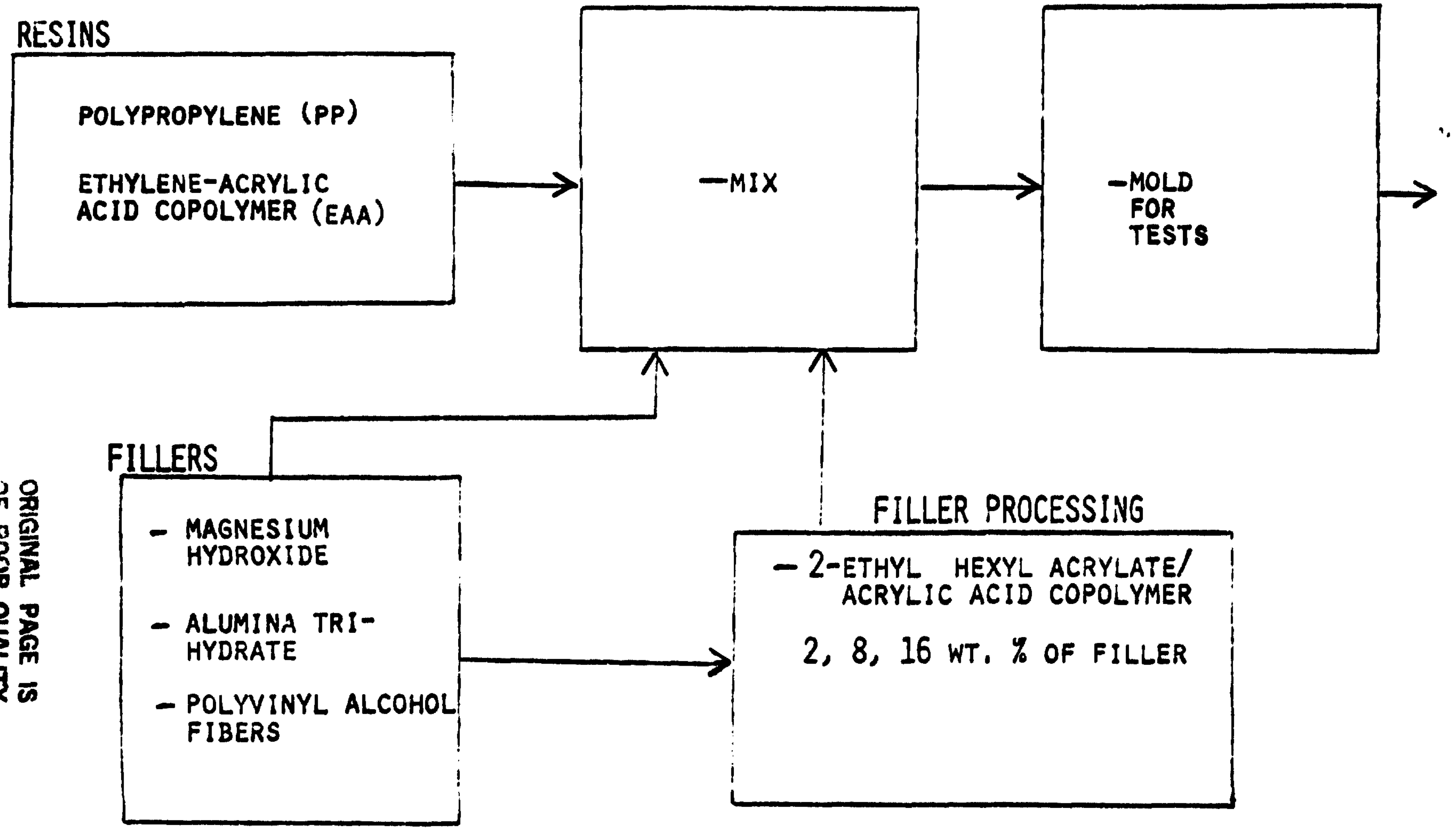


REQUIREMENTS -

- COATING MUST HAVE LOW T_g, $< -40^{\circ}C$
- BONDED TO FILLER AND RESIN
- CONVENIENT PROCESSING

THE RESINS SELECTED FOR INVESTIGATION WERE POLYPROPYLENE (PP) AND ETHYLENE-ACRYLIC ACID COPOLYMER (EAA). MAGNESIUM HYDROXIDE AND ALUMINA TRIHYDRATE ARE EXAMPLES OF ACTIVE MINERAL FILLERS THAT ARE STABLE AT THE REQUIRED PROCESSING TEMPERATURES. POLYVINYL ALCOHOL FIBERS OFFER RELEASE OF WATER ON DECOMPOSITION, LIGHT WEIGHT, AND ARE KNOWN TO IMPART EXCELLENT IMPACT RESISTANCE TO THERMOPLASTIC POLYESTER MOLDING COMPOUNDS. 2-ETHYLHEXYL ACRYLATE-ACRYLIC ACID COPOLYMER BONDS READILY TO MAGNESIUM HYDROXIDE AND ALUMINA TRIHYDRATE, AND IS COMPATIBLE WITH THE RESINS.

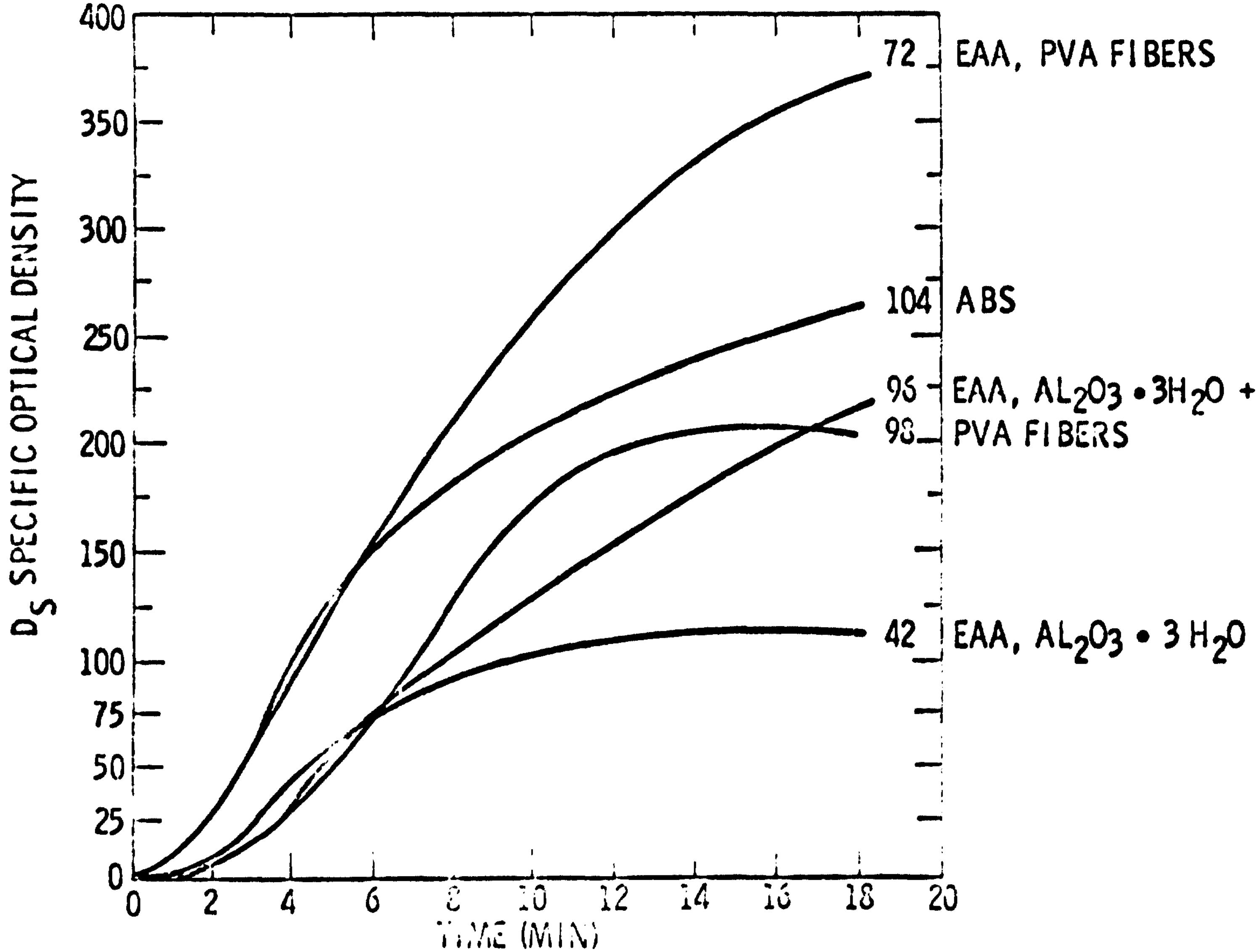
EXPERIMENTAL PLAN



D/5

BEST RESULTS UNDER NON-FLAMING CONDITIONS ARE WITH EAA-ALUMINA TRIHYDRATE. PVA FIBERS CAUSE MUCH SMOKE, MORE THAN ~ SMOKY ABS. THESE SAMPLES ALL SHOW SATISFACTORY IMPACT RESISTANCE.

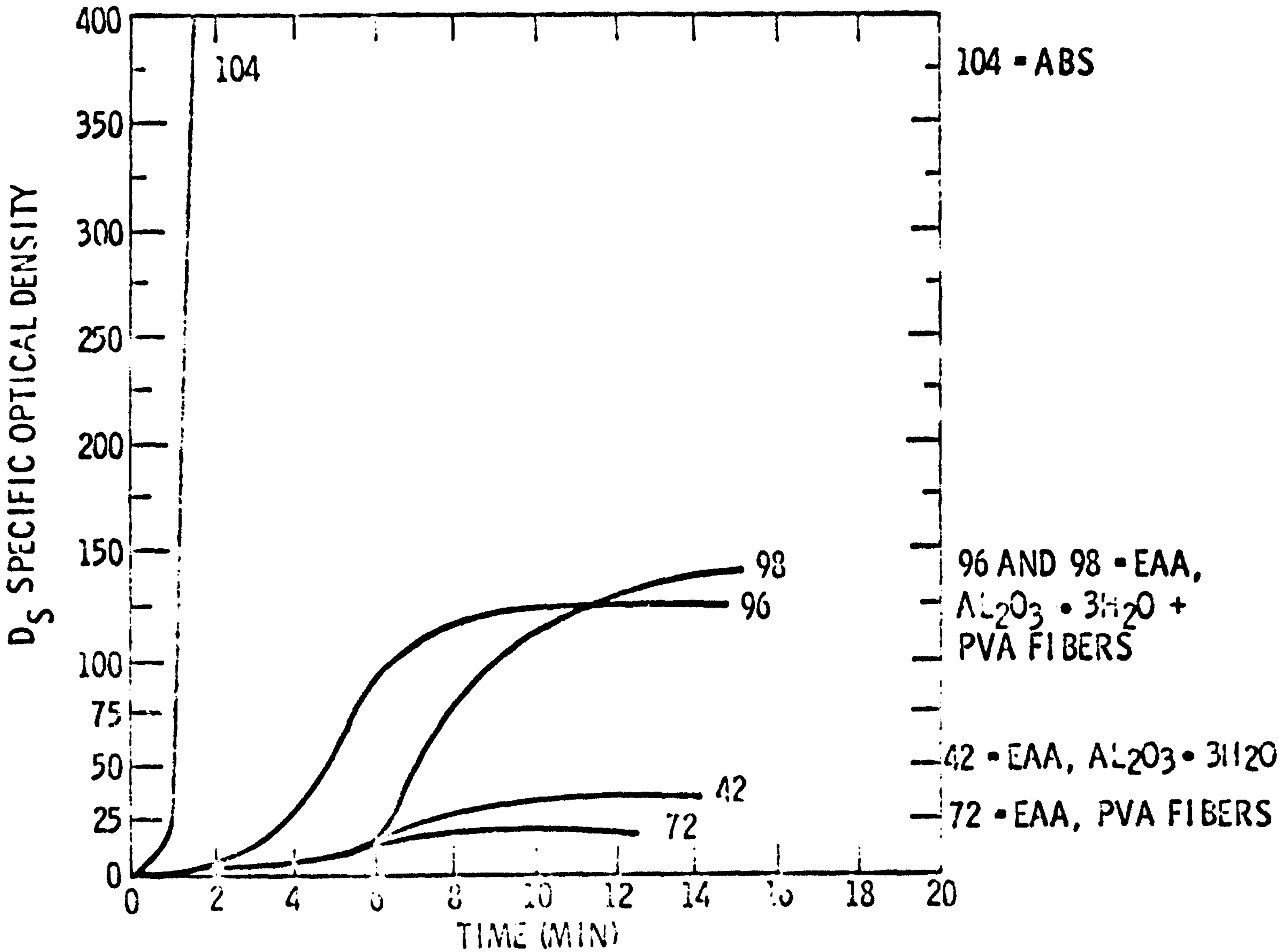
SMOKE GENERATION — NON FLAMING
(NBS SMOKE CHAMBER)



RESULTS UNDER FLAMING CONDITIONS ARE MARKEDLY DIFFERENT FROM NON-FLAMING CONDITIONS. THE EAA/PVA COMBINATION, THE BEST UNDER FLAMING CONDITIONS, IS THE WORST UNDER NON-FLAMING CONDITIONS. THE EAA-ALUMINA TRIHYDRATE COMBINATION, WHICH WAS THE BEST IN NON-FLAMING CONDITIONS, IS ALSO VERY GOOD IN FLAMING CONDITIONS. NOTE THAT MIXTURES OF ALUMINA TRIHYDRATE AND PVA FIBERS ARE SUBSTANTIALLY WORSE THAN EITHER ALONE. THIS MAY BE CAUSED BY A CHANGE IN THE MECHANISM OF DECOMPOSITION.

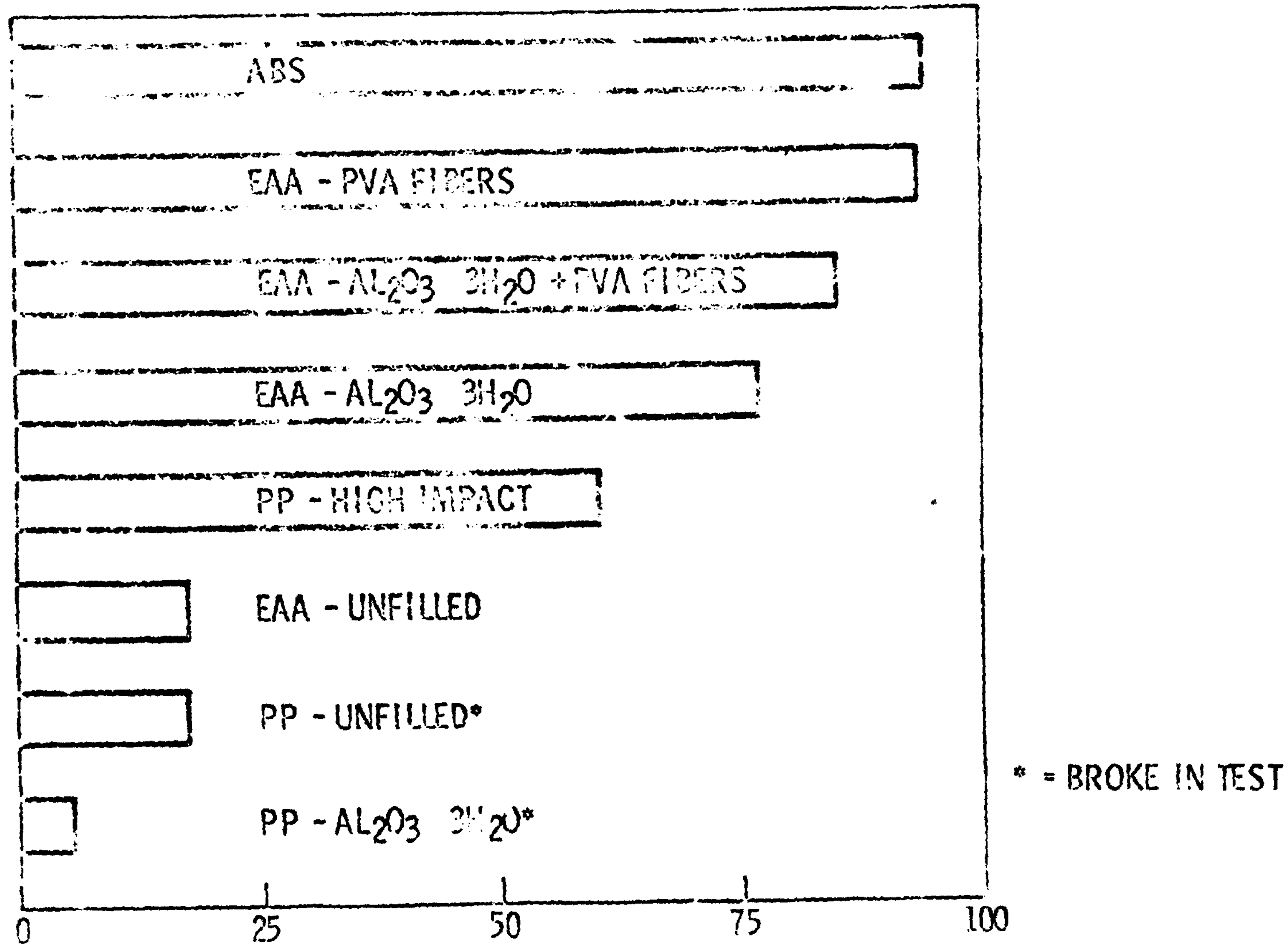
SMOKE GENERATION — FLAMING

(NBS SMOKE CHAMBER)



THE RESIN-MINERAL FILLER COMBINATION WITH THE BEST IMPACT PROPERTIES WAS EAA-ALUMINA TRIHYDRATE. A FILLER COATING LEVEL OF 8% GAVE THE BEST RESULTS. MAGNESIUM HYDROXIDE-FILLED MATERIALS TENDED TO BE BRITTLE. THE IMPACT RESISTANCE OF POLYPROPYLENE FILLED WITH COATED FILLERS WAS LESS THAN UNFILLED POLYPROPYLENE. POLYVINYL ALCOHOL FIBERS MARKEDLY IMPROVED THE IMPACT RESISTANCE OF BOTH PP AND EAA.

RELATIVE IMPACT RESISTANCE OF VARIOUS MATERIALS



THE USE OF HIGH LEVELS OF ACTIVE FILLERS CAN PRODUCE A MOLDING COMPOUND WITH A SATISFACTORY BALANCE OF PROPERTIES, HOWEVER A WEIGHT PENALTY IS INCURRED. THIS PENALTY IS ESTIMATED AT 200 - 250 LBS FOR AN L1011 OR 747 AIRCRAFT. PVA FIBER GIVES EXCELLENT RESULTS EXCEPT UNDER NON-FLAMING CONDITIONS. THIS MAY BE DUE TO A CHANGE IN THE MECHANISM OF DECOMPOSITION. IF SO, CATALYSIS OF THE REACTION UNDER NON-FLAMING CONDITIONS MAY REDUCE SMOKE EVOLUTION, AND ADVANTAGE COULD THEN BE TAKEN OF THE LIGHT WEIGHT OF THE PVA-EAA COMBINATION.

SUMMARY

EAA-ALUMINA TRIHYDRATE

- LOW SMOKE
- LOW TOXICITY
- LOW COST
- SATISFACTORY IMPACT RESISTANCE
- WEIGHT PENALTY (200 - 250 LBS)

EAA-PVA

- LOW TOXICITY
- HIGH IMPACT RESISTANCE
- WEIGHT BENEFIT (125 - 150 LBS)
- LOW SMOKE UNDER FLAMING CONDITIONS
- HIGH SMOKE UNDER NON-FLAMING CONDITIONS

THERMOCHEMICAL MODELING

505-08-25

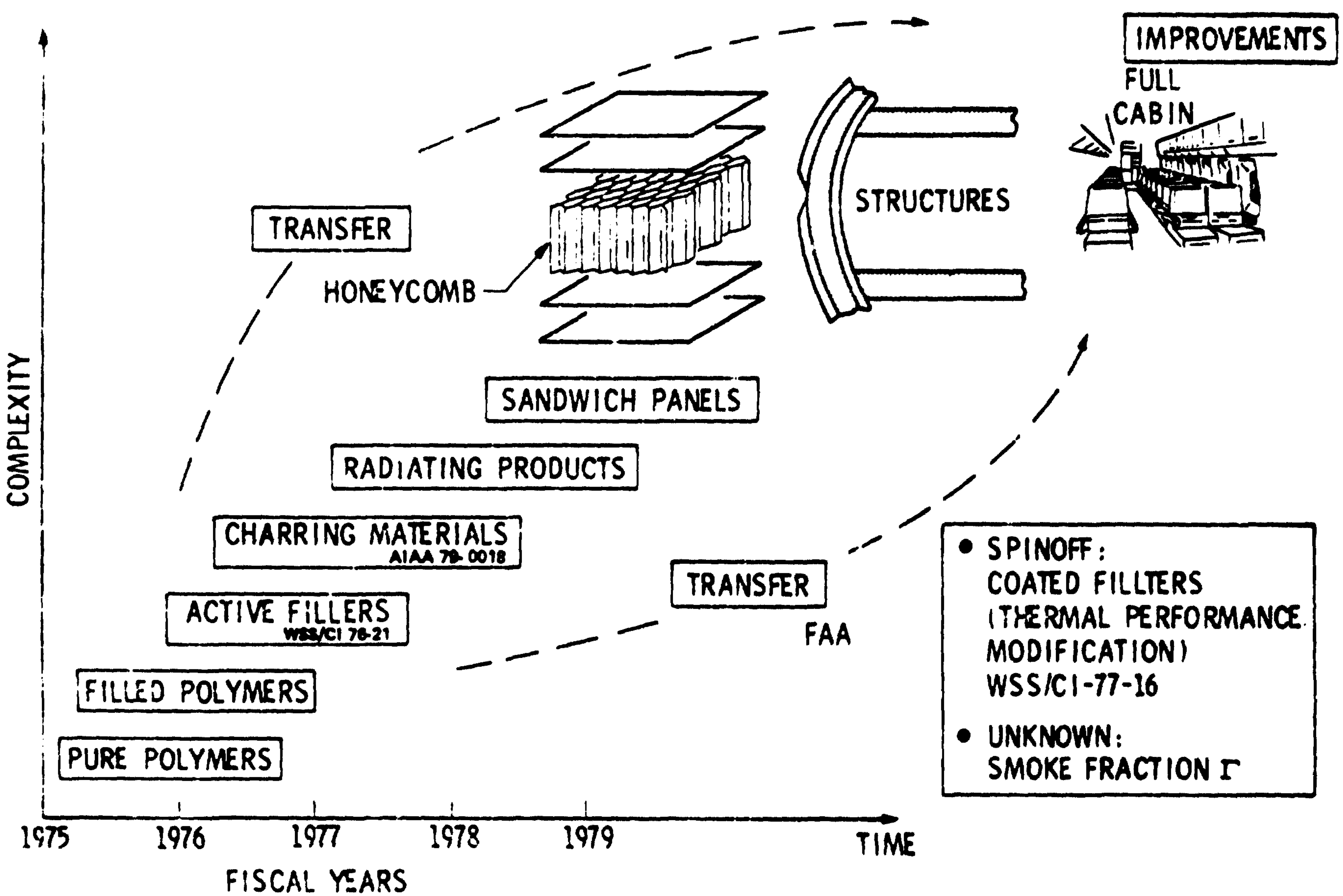
KUMAR RAMOHALLI

MARCH 1, 1979

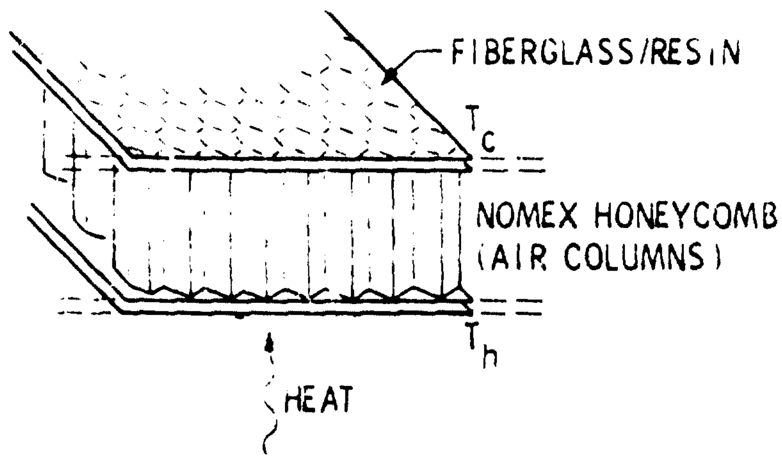
- AIMS
  - PREDICT FIRE AND SMOKE BEHAVIOR USING ONLY
    - INGREDIENT THERMOCHEMICAL PROPERTIES
    - GEOMETRY AND FLOW

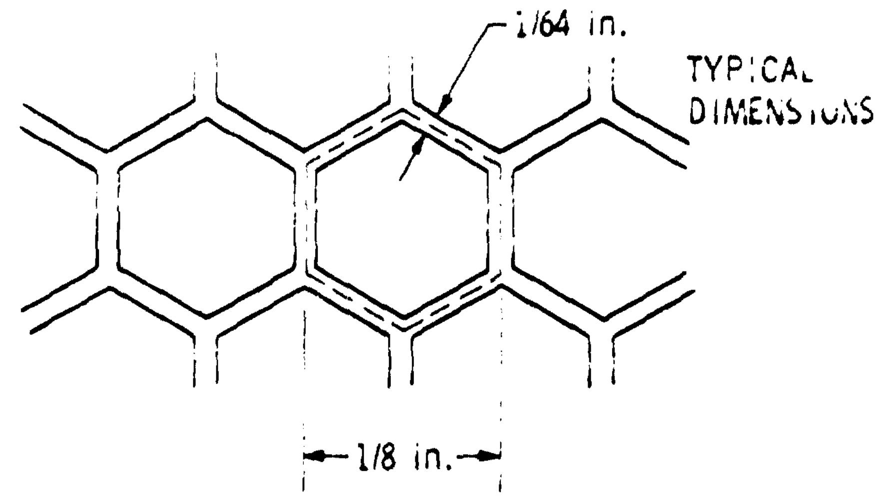
    } NON-EMPERICAL
  - SUGGEST ECONOMICAL METHODS FOR BETTER MATERIALS
  - TRANSFER TO INDUSTRY
- PROGRESSIVE STEPS IN COMPLEXITY

PLAN OF PROGRAM



HONEYCOMB SANDWICHES





- CONDUCTION:

SOLID NOMEX: $k_{nomex} \times A_{nomex} \simeq 0.092 \times 0.0024 = 2.2 \times 10^{-4}$

AIR COLUMNS: $k_{air} \times A_{air} \simeq 0.020 \times 0.01 = 2.0 \times 10^{-4}$

RATIO ~ 1

  - SIMPLIFICATIONS NOT FEASIBLE

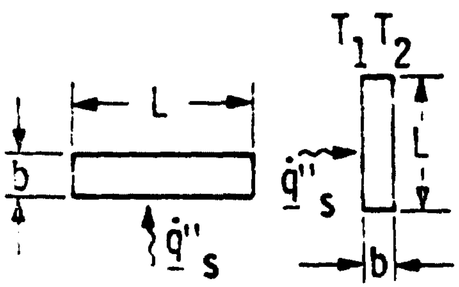
- CONVECTION

$$\underset{\text{Rayleigh Number}}{R} = \underset{\text{Grashof Number}}{G} \cdot \underset{\text{Prandtl Number}}{P_r} = \frac{g\beta\partial_w X^3}{\nu^2} \cdot \frac{\mu c_p}{k}$$

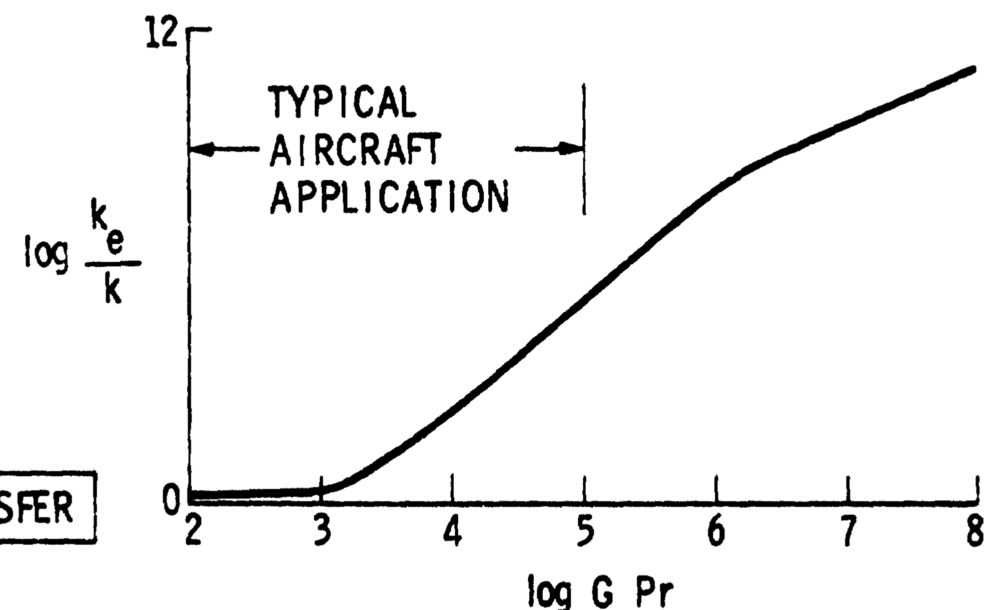
< 1700 NO CONVECTION
1700-47000 CELLULAR
>47000 TURBULENCE

APPROACH

- AVAILABLE SOLUTIONS AND EXPERIMENTS



$$\boxed{\underline{q} = \frac{k_e}{b}(T_1 - T_2)}$$



SIGNIFICANT INCREASE IN HEAT TRANSFER

- SOLUTION FOR SPECIFIC CASE NOT AVAILABLE
- CHEMICAL DEGRADATION
- DEBONDING
- GAS EVOLUTION AND FLOW

SUMMARY
(Feb 1979)

- COMPLEX CHARRING CASE SOLVED
- CONFIRMED BY EXPERIMENTS

} AIAA PAPER 79-0018

- PROBLEMS IDENTIFIED IN SANDWICH PANELS
- FORMULATION COMPLETED

- SPINOFFS
  - APPLICATIONS IN GRAPHITE FIBER COMPOSITES
  - THERMAL PERFORMANCE CONTROL (COATED FILLERS AND PROPELLANTS)

D17

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N79-31183

isovolta

H. WERFK

The fluorenon polyester ISO FPE of ISOVOLTA Comp... Austria

In the last two years the Isovolta Comp. has payed attention to a family of polymers which are thermally stable, of low flammability and which show in the case of combustion a low toxic gas emission. The aim was to cast a transparent film of a solution, in which no flame retardants are used to achieve the flammability requirements.

ISO FPE consists only of carbon, hydrogen and oxygen, that is to say that no nitrogen, fluorides, sulfur or antimony are incorporated in the polymer.

The selection of monomers was based on the aspects shown in previous papers, namely that the char yield and the amount of incombustible gases formed in thermal decomposition are the most significant characteristics of flame resistance, even in a quantitative way. For a large number of well known polymers the char yield under nitrogen atmosphere due to pyrolysis was determined. The char yield is related to the chemical structure of the polymer in a distinct way. Also, the amount of char yield can be predicted from the structure. Secondly, there is a significant relation between the char yield and the limiting oxygen index. The LOI is measured according to ASTM D 2863-76.

The linear correlation between the char yield Y_c^{800} under nitrogen atmosphere and the LOI is represented by the equation:

$$LOI = 17{,}5 + 0{,}4 \cdot Y_c^{800}$$

The char yield Y_c^{800} under nitrogen atmosphere is related to the chemical structure of the polymer by the equation :

$$Y_c^{800} = 1/M \cdot 1200 \cdot \sum_i (CFT)_i$$

M means the molecular weight per structural unit

(CFT) the group contributation to the char forming tendency

The experimental results mach the theoretical values very well. Doing a thermogravimetric analysis a char yield of 58 % weight retention is found(Fig 1). This causes a theoretical LOI of 40,7 %, the value found by experiment is 40.

The group contribution to the char forming tendency is shown in the following table.

Group			Constribution to CFT (modified)
methyl	CH_3-		- 1,5
methylene	CH_2=		- 1
isopropylidene	$C(CH_3)_2$=		- 3
phenyl	C_6H_5-		+ 1
phenylene	C_6H_4=	o	+ 2
		m	+ 3
		p	+ 4
fluorene-9-ylidene			+ 10

This table allows to predict the flammability behaviour of groups used to compose monomers.

In a comprehensive study of P.W.Morgan a large number ob bisphenols was studied. However, only two of these bisphenols showed sufficient quality of polymers resulting in a high value of LOI. This fact is due to the missing of groups with negative contribution to the char forming tendency. The monomer engaged for the preparation of ISO FPE is the 9,9-Bis(4-hydroxyphenyl)fluorenone, or fluorenone, which we call Diphenol F.

Diphenol F is prepared by a modification of the synthesis of Morgan in batches of 100 lb from fluorenone, phenol, hydrogen chloride and a co-catalyst. The synthesis is conducted by Isovolta Company in Austria. The yield of Diphenol F after one crystallisation process from 1,2 dichloroethane, is more than 90 percent.

Technical datas are shown in the table below:

Melting point	:	225°C		
Elemental analysis	:		% C	% H
		calculated	85,69	5,18
		experimental	85,54	5,03

The purity of Diphenol F is checked by high pressure liquid chromatography and yields a value of 99 percent.

Synthesis of ISO-FPE

One of the most common syntheses of polyesters is the reaction of chlorides of dicarboxylic acids with bisphenols. However, there are several ways described in the literature to conduct the synthesis of these polyesters:

The LOI of polyesters produced by solution condensation at high temperatures yields a low value compared to polyesters prepared with solution condensation at room temperature. The reason is, that even a low concentration of products which is obtained by decomposition due to these drastic temperature conditions causes the low value of LOI.On the other hand, the interfacial condensation is carried out at room temperature. Since Diphenol F shows a low solubility in aqueous sodium hydroxyde a solution condensation with stoichiometric amounts of hydrogen chloride acceptors - such as triethylamine or others - is preferred when working at room temperature. The advantage of this process is, that low boiling solvents such as dichloromethane or 1,2-dichloroethane are applicable at normal pressure. High molecular weight of the polyester is only obtained by the use of terephthalic and isophthalic acid chlorides of high purity.

With respect to mechanical properties we obtained the best results using a mixture of terephthalic and isophthalic acid chlorides within the range of a 1:1 to 3:1 mixture. Films cast from solutions of polyesters synthesized only with one of these two acid chlorides show brittleness.

The melting range of ISO-FPE is close to the heat distortion temperature at 480°C. Due to this fact and the high temperature resistance ISO-FPE is not suitable for injection molding and extrusion. ISO-FPE shows good mechanical and electrical properties over a wide range of temperature and frequency (see Fig 2). ISO-FPE is soluble in dichloromethane, chloroform, 1,2-dichloroethane, 1,1,2,2-tetrachloroethane, trichloroethylene, dimethylformamide, dimethylacetamide, cresol, tetrahydrofurane and methyl benzoate.
ISO-FPE is insoluble in water, acetone, methanol, ethanol, isopropanol, ethyl acetate and benzine.

Combustion of ISO-FPE coatings and films yields very low smoke and toxic gas generation. As shown in Fig 3 ISO-FPE produces some CO and CO_2, which are within the permitted ranges and no HF. The flame spread data according to ASTM E - 162 are given in Fig 4 and the smoke production in Fig 5. In both cases the film is compared with the data of a PVF film of same thickness.

Production of Powder and Films

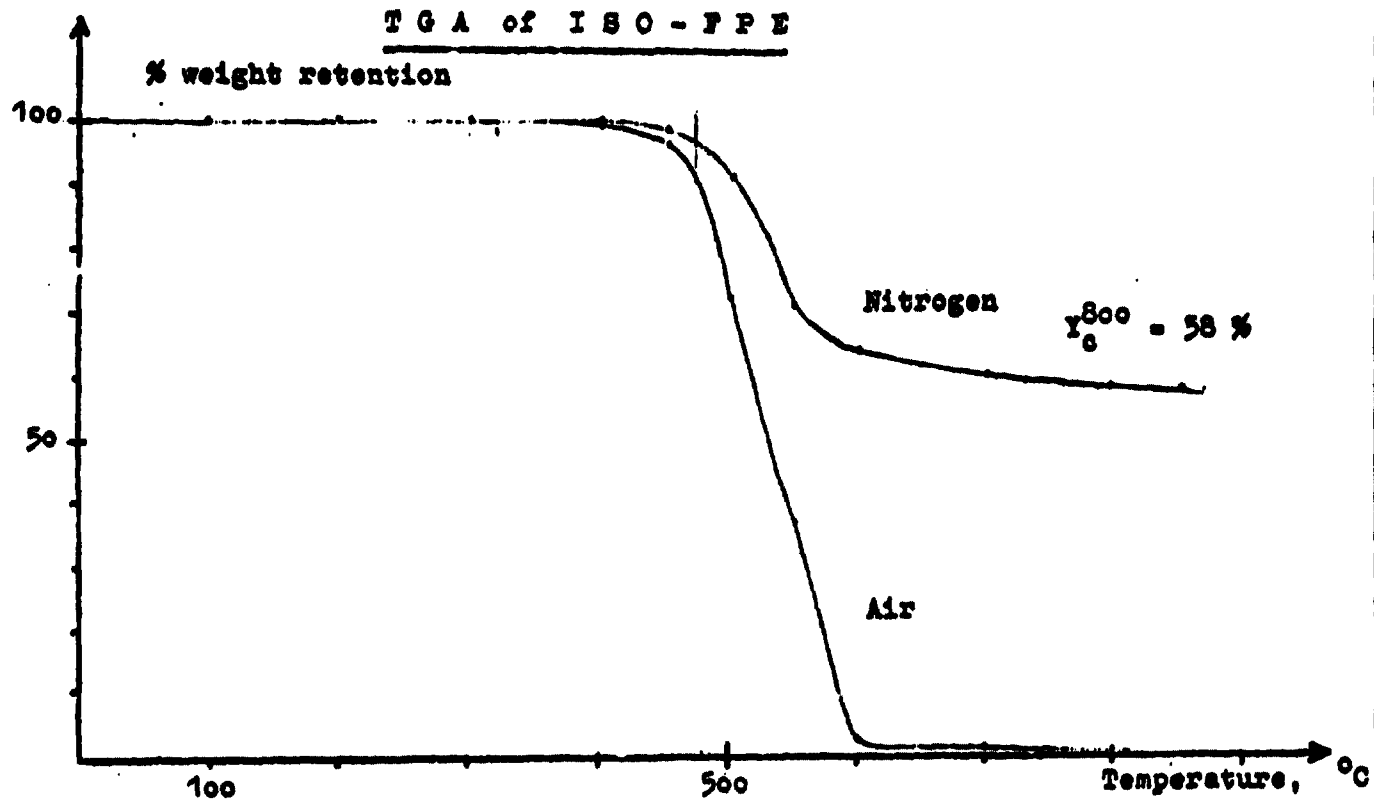
After synthesizing ISO-FPE polyester in a laboratory scale we looked for a possibility to process the polyester in batches of some pounds. Therefore, a small pilot plant was developed to work with both the solution condensation method and the interfacial condensation method. This pilot plant is a sort of universal tool adaptable to the actual needs. The conditions of a small scale production could be studied with this machine. Now, batches of 40 pounds of polyester can easily be obtained in a second generation pilot plant. However, the preparation of pure, high molecular weight polyester demands a lot of tedious hand labour at the moment, restricting our output to one batch a week.

In spite of these and other difficulties we have been able to cast films in a continous process on a laboratory film casting machine using a 200μ Teflon foil as substrate. Plans are under consideration for a pilot plant equipment with a production of up to 20 tons of polyester per year.
Currently films are available in thicknesses from 1/4 of a mil up to 3 mil. In Addition preliminary studies have been conducted to evaluate the adhesive performance of various deco ative inks on the film. The film may be embossed at temperatures between 100 and 180°C under a pressure of 290 psi using conventional pressing techniques.

The film can be pigmented with various inert inorganic pigments such as Ti O_2 and various tinting agents and colorants. Furthermore, preliminary tests were conducted to evaluate the soil and smoke resistance according to Boeing standards which are shown in Fig 6.

As a conclusion we think that the ISO-FPE film has a potential use as a corative fire resistant film for aircraft interior application. However, additional work is required to evaluate this film in conjunction with current state of the art aircraft interrior panels and other advanced structures.

Thank you for your attention.



Thermogravimetric Analyses of I S O - F P E under nitrogen and air
Figure 3

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Properties of I S O - F P 3

Test			Average Value
Powder			
Glass transition temperature		°C	none
Melting range		°C	none
Heat distortion temperature		°C	48o
Inherent viscosity		$dl.g^{-1}$	o,6o
(phenol : tetrachloroethane = 6o : 4o			
o,5 g / 1oo ml)			
Film			
Thickness		mm	o,o5o
Density		$g.cm^{-3}$	1,22
Tensile strength		$Pa.1o^{5}$	662
Elastic modulus		$Pa.1o^{1o}$	o,21
Elongation		%	4,2
Dielectric strength		$kV.mm^{-1}$	286
Dielectric constant	1oo Hz		3,55
	1 kHz		3,52
	1 MHz		3,7o
Dissipation factor	2oo Hz		$25,o . 1o^{-3}$
	1 kHz		$8.o . 1o^{-3}$
	1 MHz		$17,2 . 1o^{-3}$
Volume resistivity	5oo V	Ω.cm	$1,o . 1o^{17}$
Surface resistance	1ooo V	Ω	$6,o . 1o^{11}$
Weight loss after 24 hrs, 25o °C		%	1,48
Water absorption		%	< o,5
Solder float test (26o °C)		s	> 12o
Char yield Y_c^{8oo}, nitrogen		%	58
Limiting oxygen index		%	36
film, 125 µ, room temp., vacuum			
Rod			
(sintered at 22o °C under pressure)			
Limiting oxygen index		%	4o

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Technische Mitteilungen

Elektro-Isolierstoffe

Flexible Isolierstoffe

Toxic Gas Evolution of I S O - F P E - Film

N B S Chamber 4,o min

Film

o,oo1 inch Densil adhesive

3-ply laminate
(Ciba Geigy 971 G/1581)

	Tedlar o,oo2 inch	I S O - F P E o,oo2 inch
NO_x, ppm	7	2
C O	1oo	12o
CO_2	18oo	18oo
H F	1o2	o

isovolta
Österreichische Isolierstoffwerke Aktiengesellschaft

Verkauf: A-2351 Wiener Neudorf, Wiener Straße 17
Tel. [illegible], Telex [illegible]

Flame Spread Data of I S O - F P E - Film

ASTM E - 162

Film

o,oo1 inch Densil adhesive

3-ply laminate
(Ciba Geigy 971 G/1581)

	I s	S.D.[x]
3-ply laminate + o,oo1 inch Densil adhesive	2,65	o,6o
o,oo2 inch Tedlar	1,82	o,43
o,oo2 inch I S O - F P E	2,oo	o,4o

S.D.[x] Standard Deviation

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Smoke Measurements of I S O - F P E - Film

N B S - Smoke Chamber 2,5 W/cm²

	Specific Optical Density (Flaming Condition)		
	D s 1,5 min	D s 4,0 min	D m (max)
Tedlar o,oo2 inch	6,67	11,o7	15,13
I S O - F P E o,oo2 inch	1o,93	16,27	18,7o

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Soil Resistance and Smoke Stain Resistance of

I S O - F P E - Film

Tested by Boeing Material Specification 8 - 22o

Items : butter
mayonnaise
chocolate
soup
fruit stain (orange juice)

cigarette smoke (168 hours)

Washing agents : SU 126 SYRO (Unilever) 1o % solution
SU 9o4 JET (Unilever) 1o % solution

I S O - F P E - Film (o,oo2 inch) shows no discoloration when soiled and cleaned in accordance with Boeing Material Specification, Section 8.3. and 8.4.

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OMIT TO END

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